ENERGY CONSERVATION IN THE INDUSTRIAL MINERAL SECTOR – COMMINUTION –

Prepared for:

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Energy, Mines and Resources Canada

Volume III

Mica
Nepheline Syenite
Potash
Silica
Talc
Phase II Lab. Reports

CANADA CEMENT LAFARGE LTD.
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VOLUME III

Mica Nepheline Syenite Potash
Silica Talc
Phase II Lab. Reports

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THE MICA INDUSTRY

ENERGY CONSERVATION IN THE INDUSTRIAL
MINERALS PROCESSING SECTOR - COMMINUTION

(Phase I - Plant Studies)

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1. General Information
2. Product Characteristics
3. Quality Criteria

REFERENCES

1. INTRODUCTION

Cooperating Company:

Marietta Resources International Ltd.

Plant Location:

Boucherville, Quebec

The report introduces first the company that cooperated in the study. A description follows of the comminution processes monitored during the field work at the company's plant. The measurements made and results obtained are then reported and discussed and conclusions drawn.

For readers who are not familiar with the Mica industry, an appendix entitled "Industry Review" is added.

Details concerning data collection and field work, as well as other raw data or measurements, are available in the working papers.

Marietta Resources International Ltd, (MRI) is a joint venture between Société Minéralurgique Laviolette Inc., Montreal and Martin Marietta, Bethesda, Maryland. MRI is operated as part of Martin Marietta Basic Products whose headquarters are in Hunt Valley, Maryland and is the world's largest producer of mica for the plastics industry.

The company consented to the use of its Boucherville, Quebec plant to gather the necessary data required for this study.

2.1 General

Mica is a group name for some nine minerals, two of which muscovite and phlogopite are the raw materials used by the mica industry. All micas are complex hydrous silicates with varying proportions of magnesium, potassium and aluminum. Mica possesses special physical, mechanical, electrical and thermal properties. Some uses are in thermoplastics, asphalt and cement products, the electrical and electronics industry, paints, greases, mold lubrication, absorbants and in oil well drilling muds.

The original Siscoe mica deposit was discovered in 1931. The location is approximately 2 miles south west of the present mined deposit, which is just north of Parent, Quebec in Suzor Township.

In 1960, Société Minéralurgique Laviolette Inc., acquired ownership of the original mine and in the same year discovered the present Bedard deposit.

There are over 30 million tonnes of 85-95% pure ore in the Bedard deposit; about double the purity of the original Siscoe mine.

In 1972, a decision was made to build a pilot plant in the Pointe St-Charles district of Montreal. This became operational in 1973, and after several modifications and expansions, a decision to build a full-scale production plant was made.

In 1976, construction of the plant began and in late January 1977, it was commissioned, but with limited production.

In 1978, the production increased considerably and subsequently doubled in 1979 to about 11,000 tonnes per year. It has remained near to this level since.

The plant processes about 15,000 tonnes of ore annually, depending on the product mix.

Geographical distribution of sales are:

25%	Domestic
60%	United States
15%	South America, Europe and Japan

2.2 Products Marketed

MRI produces three main types of mica products: Z, S and FE. From these, about 20 different classifications, based primarily on purity, degree of fineness and aspect ratio,* are marketed.

* Aspect Ratio: the average diameter of a flake divided by its thickness.

From 1978 to 1983, the demand has changed from coarse "Z" to fine "FE" products as the need for filler material increased.

Shipments are either bulk or bagged, which are palleted and wrapped. During bulk loading a sample is taken from each ton and during bagging at every 20th bag. Size distribution, bulk density and sieve analysis tests are run to monitor the quality of the product.

3.1 Mica Process Flow

An overview of the MRI process is shown on the flow sheet, Figure I.

Comminution in the true sense is a limited operation except in the primary crushing stage, which receives the mined ore from the stockpile. Elsewhere, the impact crusher and pin mill are used to delaminate the flakes.

The main processing operations are crushing, drying, screening and sifting. The three broad classes of products result from sequential phases of the process.

"Z" Products

High-purity ore from the Bedard mine is locally crushed to a maximum 23 cm diameter, then trucked to the railhead at McCarthy, Quebec where it is shipped to the Boucherville plant and stockpiled.

The ore is retrieved from the stockpile by front-end loader and is dumped onto a belt conveyor and transported to the primary jaw crusher, and reduced to a maximum diameter of 5 cm. The process is outlined on the flow sheet, Figure II, and the equipment in Table 1.

The crushed ore is transported via conveyor and bucket elevator to a feed bin which then discharges it into a rotary dryer, where the moisture content is reduced from about 6% to between 0.2 and 0.5%.

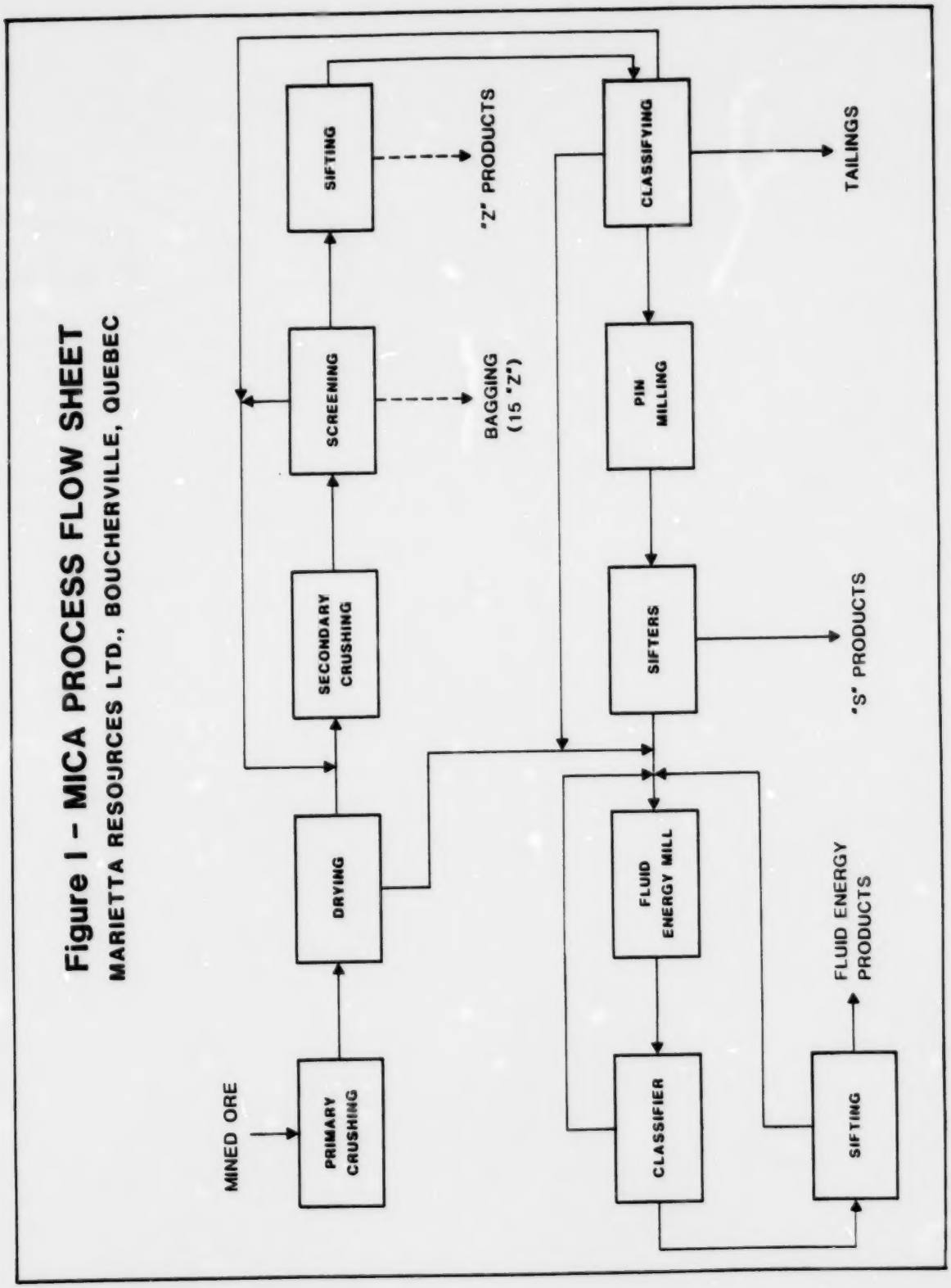


Figure I - MICA PROCESS FLOW SHEET
MARIETTA RESOURCES LTD., BOUCHERVILLE, QUEBEC
MINED ORE
PRIMARY CRUSHING
DRYING
SECONDARY CRUSHING
SCREENING
SIFTING
"Z" PRODUCTS
BAGGING (15 "Z")
CLASSIFYING
TAILINGS
PIN MILLING
SIFTERS
"S" PRODUCTS
FLUID ENERGY MILL
CLASSIFIER
SIFTING
FLUID ENERGY PRODUCTS

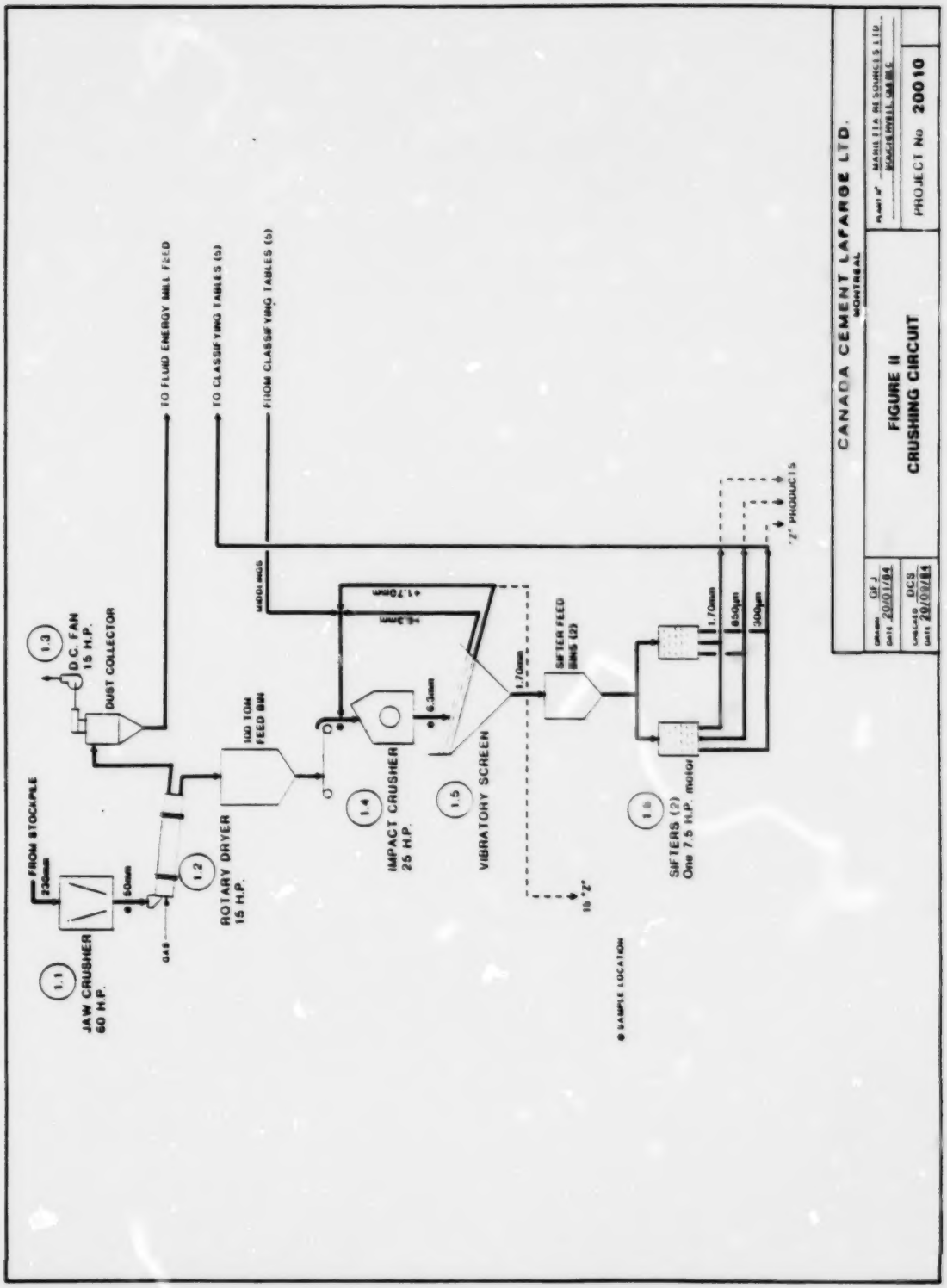

CANADA CEMENT LAFARGE LTD.
MONTREAL
FIGURE II
CRUSHING CIRCUIT
PROJECT No 20010
DRAWN QF J DATE 20/01/84
CHECKED DCS DATE 20/01/84
1.1 JAW CRUSHER 60 H.P.
1.2 ROTARY DRYER 15 H.P.
1.3 D.C. FAN 15 H.P.
DUST COLLECTOR
1.4 IMPACT CRUSHER 25 H.P.
1.5 VIBRATORY SCREEN
1.6 SIFTERS (2) One 7.5 H.P. motor
FROM STOCKPILE
230mm
50mm
6.3mm
1.70mm
850µm
300µm
100 TON FEED BIN
SIFTER FEED BINS (2)
TO FLUID ENERGY MILL FEED
TO CLASSIFYING TABLES (5)
FROM CLASSIFYING TABLES (5)
MODIFIED
TO "2"
"2" PRODUCTS
SAMPLE LOCATION

TABLE 1 - Crushing - Equipment List

No.	EQUIPMENT TYPE/MAKE/MODEL	MOTOR* HP	MOTOR* AMPS
1.1	Jaw Crusher	60	59
1.2	Dryer	15	15
1.3	Dryer Dust Collector Fan	15	14.5
1.4	Impact Crusher	25	24
1.5	Vibratory Screen (Air Operated)	-	-
1.6	'Z' Product Sifters	7.5	7.8

* All motors are 550 volts.

The fines in the dryer are air-swept to the dust collector and become part of the fluid energy (FE) mill feed.

The remaining dried material is moved by belt conveyor and bucket elevator to a 91 tonne bin which feeds an impact crusher. The crusher discharge (6.3 mm) is fed to an air-operated vibratory screen where the oversize and the middle cut are recirculated back to the secondary crusher. In some instances the impure 6.3 mm middle size material is bagged and sold to a limited market. The fine material (1.7 mm) is sent to a feed bin which feeds the first set of sifters. The sifters can produce three products 20Z, 40Z, 60Z, or the material can continue on to the classifying tables.

"S" Products

The classifying tables are designed to retain the mica flakes and eliminate the foreign material. The fines are drawn off to a dust collector. The accepts are sent to a pin mill, which continues to "sheet" the ore. The discharge is air swept into a dust collector, whose discharge passes on to a feed bin supplying three sets of sifters.

The sifter products feed several product bins of 150S, 20S, 40S, 60S and 150 μm material.

As shown in Figure III, a composite of 40S, 60S and 150 μm material, together with the dust collector discharge from the dryer and classifying tables, becomes the feed to the Fluid Energy mill. The equipment details are shown in Table 2.

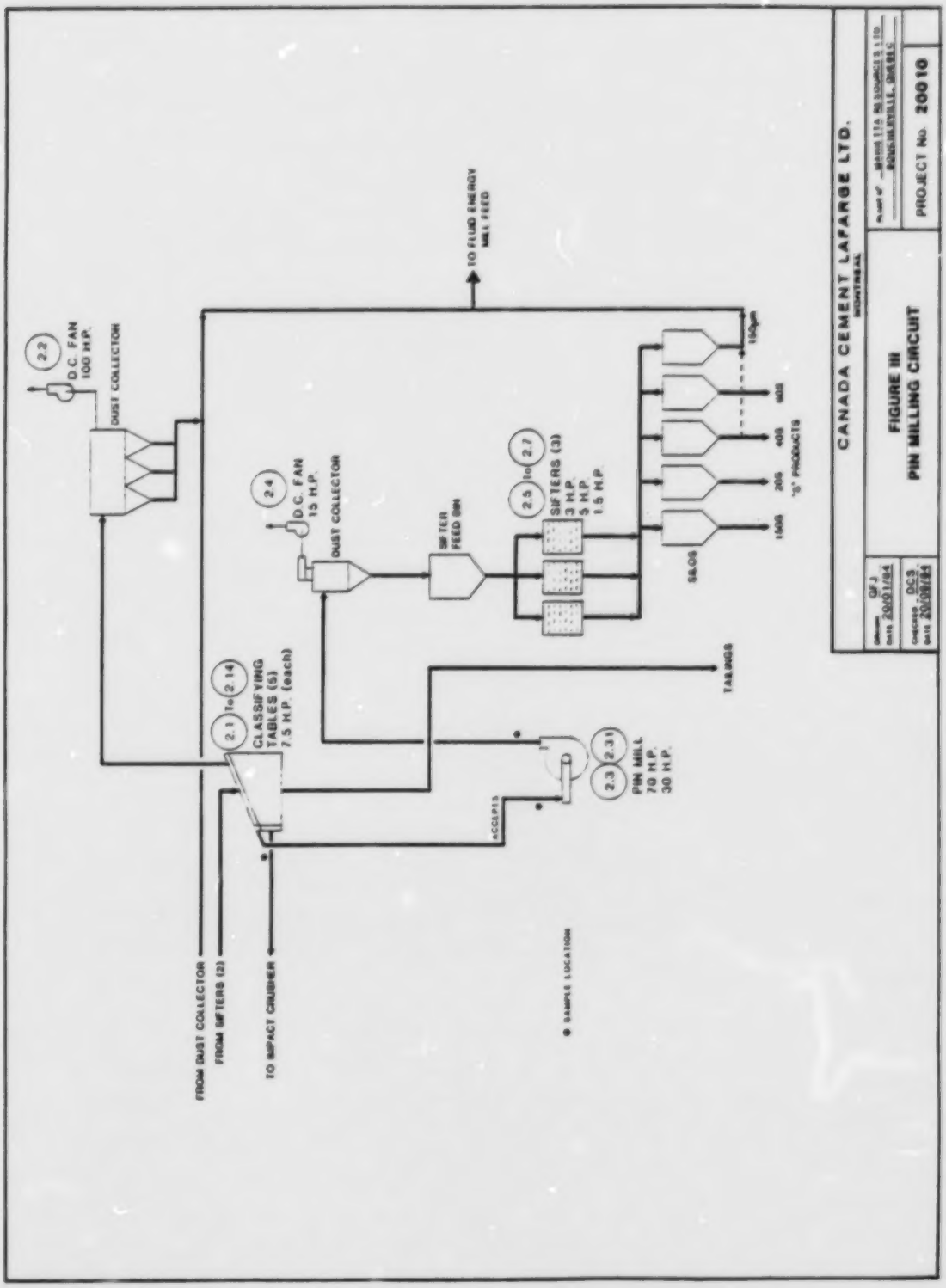
TABLE 2 - "S" Product - Equipment List

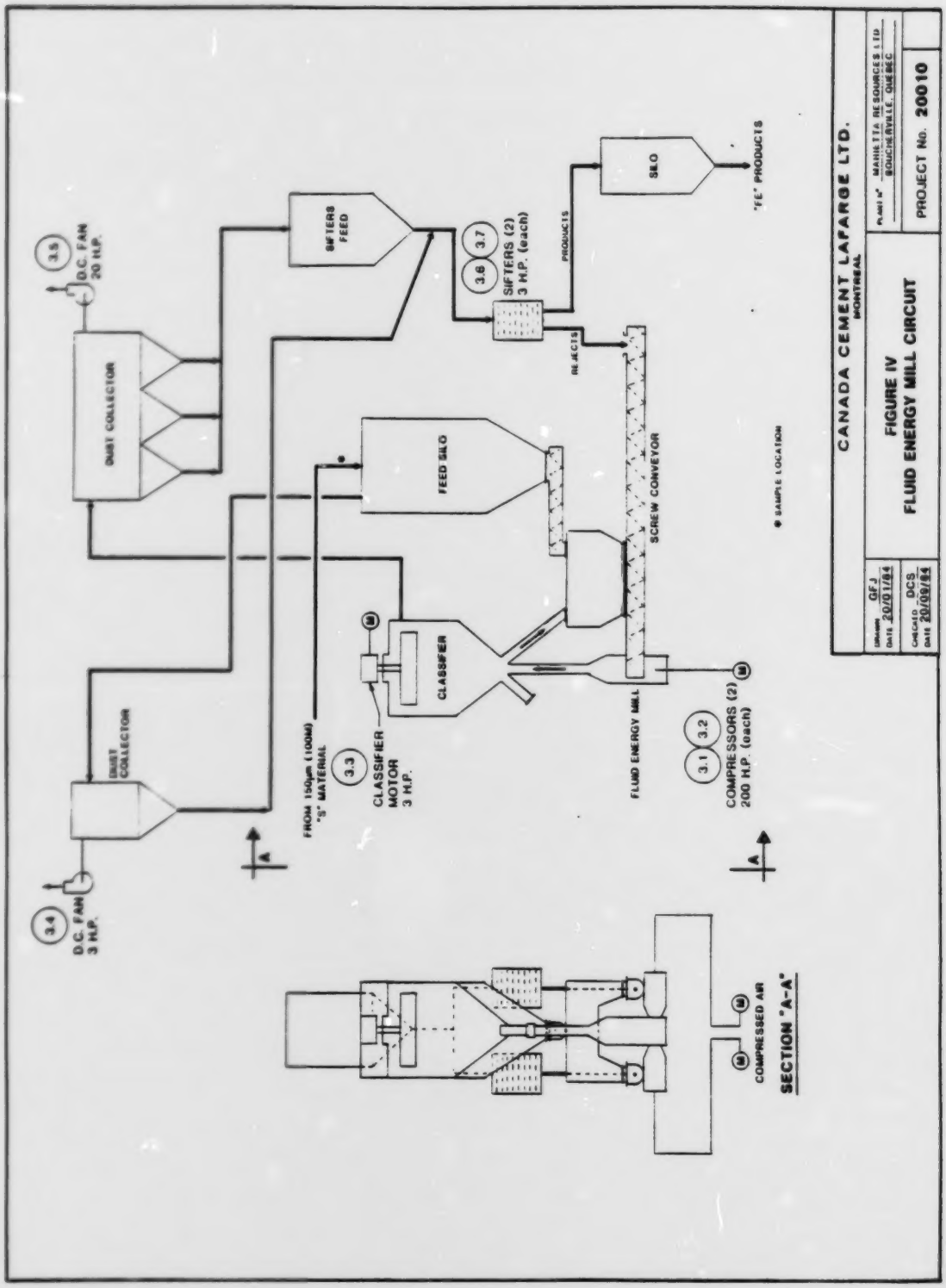
No.	EQUIPMENT TYPE/MAKE/MODEL	MOTOR* HP	AMPS
2.1	Classifying Table #1	7.5	7.8
2.11	" " " #2	7.5	7.8
2.12	" " " #3	7.5	7.8
2.13	" " " #4	7.5	7.8
2.14	" " " #5	7.5	7.8
2.2	Classifying Table D.C. Fan	100	96
2.3	Pin Mill (Same Direction)	75	70
2.31	" " (" ")	30	29.2
2.3	Pin Mill (Opposite Direction)	75	70
2.31	" " (" ")	30	29.2
2.4	Pin Mill D.C. Fan	15	13.5
2.5	'S' Product Sifters #3	3	4.7
2.6	'S' Product Sifters #6	5	5.2
2.7	'S' Product Sifters - 150S	1.5	2.3

* Motors are 550 volts.

"FE" Fluid Energy Products

The selected "S" product and dust from the circuit dust collector are conveyed to the fluid energy silo; whose discharge is then transported by screw conveyor to a feed box from which dual screw conveyors feed the fluid energy mill. As detailed in the circuit diagram, Figure IV, and in the equipment list, Table 3, the material is classified and the oversize is recirculated back to the feed box with the fines being air swept to the fluid energy mill dust collector.


CANADA CEMENT LAFARGE LTD.
MONTREAL
FIGURE III
PIN MILLING CIRCUIT
PROJECT No. 20010
GFJ
DATE 20/01/84
CHECKED DCS
DATE 20/01/84
22
D.C. FAN
100 H.P.
DUST COLLECTOR
TO FLUID ENERGY
MILL FEED
24
D.C. FAN
15 H.P.
DUST COLLECTOR
SIFTER
FEED BIN
2.5 to 2.7
SIFTERS (3)
3 H.P.
5 H.P.
1.5 H.P.
150µm
SILOS
1505
205
405
605
"S" PRODUCTS
2.1 to 2.14
CLASSIFYING
TABLES (5)
7.5 H.P. (each)
TAILINGS
2.3 2.31
PIN MILL
70 H.P.
30 H.P.
ACCEPTS
FROM DUST COLLECTOR
FROM SIFTERS (2)
TO IMPACT CRUSHER
● SAMPLE LOCATION


CANADA CEMENT LAFARGE LTD.
MONTREAL
FIGURE IV
FLUID ENERGY MILL CIRCUIT
PROJECT No. 20010
DRAWN GFJ DATE 20/01/84
CHECKED DCS DATE 20/09/84
3.5 D.C. FAN 20 H.P.
DUST COLLECTOR
SIFTERS FEED
3.6 3.7 SIFTERS (2) 3 H.P. (each)
PRODUCTS
SILO
"FE" PRODUCTS
REJECTS
FEED SILO
SCREW CONVEYOR
SAMPLE LOCATION
DUST COLLECTOR
3.4 D.C. FAN 3 H.P.
FROM 150μm (100M) "S" MATERIAL
3.3 CLASSIFIER MOTOR 3 H.P.
CLASSIFIER
FLUID ENERGY MILL
3.1 3.2 COMPRESSORS (2) 200 H.P. (each)
COMPRESSED AIR
SECTION "A-A"

The feed silo dust collector discharge and the classifier dust collector discharge form the fluid energy sifter feed. The oversize from the sifters is recirculated back to the fluid energy mill and the fine product is delivered by screw conveyor to the FE product silos.

TABLE 3 - "FE" Product Equipment List

No.	EQUIPMENT TYPE/MAKE/MODEL	MOTOR* HP	MOTOR* AMPS
3.1	Fluid Energy Mill Compressor #1	200	184
3.2	Fluid Energy Mill Compressor #2	200	184
3.3	Classifier Motor	3	3.5
3.4	Fluid Energy Mill Small D.C. Fan	3	3.6
3.5	Fluid Energy Mill Large D.C. Fan	20	20
3.6	Fluid Energy Sifter #9	3	3.5
3.7	Fluid Energy Sifter #10	3	3.2

* Motors are 550 volts.

3.2 Packaging and Shipping

From the product bins, various blends are bagged at the main bagging station or at local units. The bags are palletized and wrapped for security and protection against moisture.

Bulk shipments are made in special pneumatic tank trucks.

3.3 Air Handling System

An oversized air handling system is required, due to the amount of fine product involved. Air flow is caused by the dust collector exhaust fan, aided by the fluid energy mill compressed air system.

3.4 Quality Control

As a general rule, 1 lb samples are taken from every 20th bag or from each tonne of bulk product. Bulk dry density and wet screen tests are run. Several other tests, such as colour, absorption, chemical analysis, etc., may be required for specific applications.

The analysis of the electrical data obtained during the study will, for clarification, be grouped according to circuit operation.

4.1 Ore Crushing and Drying Circuit

4.11 Power Observations

A summary of the power observations on the crushing circuits is shown in Table 4.

TABLE 4 - Ore Crushing and Drying Circuit Power Measurements

No.	EQUIPMENT	MOTOR HP	POWER USAGE AVERAGE kW
1.1	Jaw Crusher	60	7
1.2	Drying	15	4
1.3	Dryer D.C. Fan	15	9
1.4	Impact Crusher	25	7
1.5	Vibratory Screen (Air Operated)	-	-
1.6	'Z' Product Sifter	7.5	1

The power factor of the primary crusher fluctuated substantially under full-load and no-load conditions. An average was derived and used for the power requirement calculation. However, the impact crusher operated consistently at a high power factor, as illustrated in Table 5.

TABLE 5 - Crusher Power Level

CRUSHER	kW DEMAND LEVEL (%)	
	Low	High
Jaw	30	99
Impact	99.9	99.9

4.12 Flowrates

Plant records for the year 1983 indicate that the average flowrate from the stockpile into the mill is 6.6 tonnes per hour (6.0 tonnes per hour dry).

4.13 Size Distribution

Average size distributions obtained from plant records for the material at the two crushers are as shown in Table 6. Nominal feed size to the primary crusher is 228.6 mm.

TABLE 6 - Size Distribution - % Passing

SIZE	PRIMARY CRUSHER	SECONDARY CRUSHER		PRIMARY SCREEN	
mm	Discharge	Feed	Discharge	Oversize	Undersize
37.50	70	73			
6.30	30	38			
3.35			80	20	
2.36					100
2.00	10	16		Trace	
0.85			35		40
0.30			13		15

4.14 Grindability Testing

A 15% coarse product sample (containing gangue material) was sent to Canada Cement Lafarge Research and Development Laboratory to run grindability tests, by both the Hardgrove and Bond test methods and a sieve analysis.

The Hardgrove Index was determined to be 16, indicating that mica is a very hard material.

The Bond Work Index could not be measured experimentally due to the flaky nature of the mineral. It was calculated

from the Hardgrove Grindabilty Index to be 34.88 kWh/t.

The sieve analysis of the sample provided the results indicated in Table 7.

TABLE 7 - 15Z Sieve Analysis - % Passing

SIZE	% PASSING
4.75 mm	84.1
2.36	23.5
1.18	1.7
600 µm	0.7
300	0.5
150	0.3

4.15 Specific Energy Consumption

To determine the amount of specific energy being used for the circuit operation, the power in kW is divided by the estimated flowrate. In all cases average figures were used.

The results for the crushing circuit are shown in Table 8.

TABLE 8 - Ore Crushing and Drying Circuit
Specific Power Consumption

Flowrate 6.0 tonne/hour Dry Ore

	kWh/tonne	%
Comminution	2.3	50
Auxiliaries	2.3	50
Total	4.6	100

A breakdown of the auxiliaries indicates that drying requires an electrical power demand nearly equal to that required for comminution, as shown in Table 9.

TABLE 9 - Ore Crushing and Drying Circuit
Power Demand Distribution

Demand Distribution	%
Drying	45
Sifting	4

4.2 Pin Mill Circuit

4.21 Power Observations

A summary of the electrical measurement calculations are shown in Table 10.

TABLE 10 - Delamination Ciruit
Power Measurement Calculation

No.	EQUIPMENT	MOTOR HP	POWER OBSERVATION
			Average kW
2.1	Classifying Table 1	7.5	4
2.11	Classifying Table 2	7.5	4
2.12	Classifying Table 3	7.5	4
2.13	Classifying Table 4	7.5	4
2.14	Classifying Table 5	7.5	4
2.2	Classifying Tables D.C. Fan	100	45
2.3	Pin Mill (Same Direction)	70	17
2.31	Pin Mill (Same Direction)	30	3
2.3	Pin Mill (Opposite Direction)	70	26
2.31	Pin Mill (Opposite Direction)	30	6
2.4	Pin Mill D.C. Fan	15	7
2.5	Sifters #3	3	2
2.6	Sifters #6	5	2
2.7	Sifters - 150S	1.5	-

The calculations indicate that the equipment was operating at an average level of power consumption.

4.22 Flowrates

The average flowrate of 1.32 tonnes/hour of beneficiated feed to the pin mill, was determined from actual operational data provided from plant records.

4.23 Size Distribution

There is only one crushing operation involved in this circuit. It takes place when the pin mill rotors operate in opposite directions.

A comparison of the sieve analysis of the plant provided feed sample and a tested 20S product sample, are shown in Table 11.

TABLE 11 - Pin Mill Feed and 'S' Product Size Distribution - % Passing

SIZE	FEED	% PASSING '20S'
2.00 mm	82	100
1.18		33.3
600 µm		2.4
425	19	
300		1.6
150		1.0
75	1	

4.24 Grindability Testing

A sample of 20S product was taken for the Hardgrove and Bond Index test methods and for a sieve analysis.

The testing results were similar to the 15Z sample. The Hardgrove Index was 13 and the calculated Bond Index was 42 kWh/Ton.

The sieve analysis summarizes the degree of size reduction involved in the 'S' product stage.

4.25 Specific Energy Consumption

Table 12 provides the specific power consumption for the pin mill circuit.

The operation of the pin mill encompasses both crushing and delamination operations. When delamination occurs, power consumption for the auxiliaries remains unchanged but mill power consumption drops by 37%.

TABLE 12 - Pin Mill Circuit
Specific Power Consumption

	kWh/tonne	%
Comminution	24.5	31
Auxiliaries	55.1	69
Total Consumption	79.6	100
Delamination	15.4	21.8
Auxiliaries	55.1	78.2
Total Consumption	70.5	100.0

Dust collection for the circuit uses significantly more power than comminution or delamination.

4.3 Fluid Energy Mill Circuit

4.31 Electrical Measurements

A summary of the electrical measurements for the fluid energy mill circuit are shown in Table 13.

TABLE 13 - Fluid Energy Mill Circuit - Power Demand

No.	EQUIPMENT	MOTOR HP	POWER DEMAND AVERAGE kW
3.1	Fluid Energy Mill Compressor #1	200	148
3.2	Fluid Energy Mill Compressor #2	200	173
3.3	Classifier Motor	3	1
3.4	Fluid Energy Mill Small D.C. Fan	3	3
3.5	Fluid Energy Mill Large D.C. Fan	20	6
3.6	Fluid Energy Sifter #9	3	1
3.7	Fluid Energy Sifter #10	3	1

4.32 Flowrate

The 0.68 tonne/hour flowrate for this circuit is based on data obtained from plant records.

4.33 Size Distribution

Feed to the fluid energy mill is mainly 150S material as shown in Table 14.

TABLE 14 - Fluid Energy Mill Size Distribution

SIZE (μm)	% PASSING
250	96
150	45-60
75	50-65
- 75	0-10

The fluid energy mill produces very fine material ranging from 40% to plus 92% passing 45 μm.

A 325S sample was analysed by Sedigraph as shown in Figure V.

PARTICLE SIZE DISTRIBUTION

SAMPLE IDENTIFICATION MICA SUZORITE 325-S (FE)

Density ____ g/cc LIQUID ____ Density ____ g/cc Viscosity ____ cp

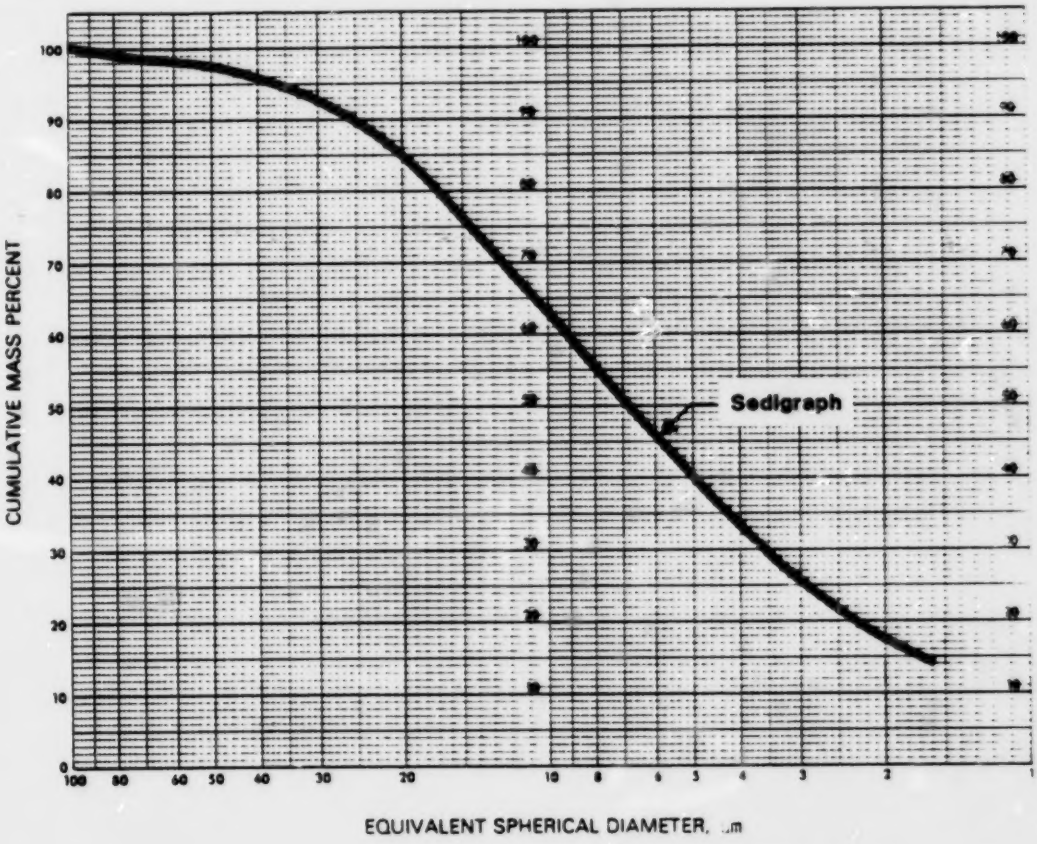
Preparation 100 seconds Sampling time

DATE March 27, 1984

BY W. Budd

TEMPERATURE ____ °C

RATE ____ START DIA ____ µm



4.34 Grindability Testing

Due to the characteristics of the mineral, no tests were run.

4.35 Specific Energy Consumption

Table 15 provides a clear understanding of how energy intensive the power demand requirement is when fine products are produced.

TABLE 15 - Fluid Energy Mill
Specific Power Consumption

	kWh/tonne	%
Comminution	471	96.5
Auxiliaries	17	3.5
Total	488	100

4.4 Plant Air Supply

The purpose is mainly for dust control and cleaning.

4.41 Specific Power Consumption

Determining the plant air system power consumption was based on the plant's hourly average production rate of 1.33 tonnes, and a power requirement of 62.2 kWh/tonne.

TABLE 16 - Plant Air Supply
Power Demand Calculations

No.	EQUIPMENT	MOTOR HP	POWER DEMAND AVERAGE kW
1	Plant/D.C. Air Compressor	100	40.2
2	Plant/D.C. Air Compressor	100	42.5

4.5 Average Cumulative Power Consumption by Product

For an overall comparison of power requirements, Table 17 was developed. It provides a clear understanding of how product fineness, beneficiation and dust collection increases the power requirements.

TABLE 17 - Average Cumulative Power Consumption

CIRCUIT	kWh/tonne		Comparison % Comminution
	Comminution	Comminution & Auxiliaries	
Ore Crushing & Drying	2	5	40
Pin Mill	27	85	32
Fluid Energy Mill	498	573	87
Total	527	663	79

From the table, total comminution is 79% of direct plant operations. However, if plant air is included, the comparison percentage is reduced to 73%. Still considerable, since production levels in the Fluid Energy circuit are increasing.

5.1 Conclusions

As a result of the study, we can conclude that the requirement for high aspect ratio and high fines below 95 μm is energy intensive.

Also, it was observed that dust collection and plant air systems are significant power consumers. Comparatively, the sifters (the equipment responsible for producing product) are low power consumers.

It is probable that significant decreases in power utilization could be achieved by using another type of fine grinding mill, better classification of fine product and by increasing production volumes through plant expansion.

Mica is extremely hard and abrasive, requiring special protective materials.

5.2 Recommendations

An effort should be made to test other types of mills, materials and classifiers which could probably reduce the cumulative product power consumption for mediocre fine and fine products.

Also, due to the low bulk density of the beneficiated mica, try locating fine grinding units near market centers.

APPENDIX

INDUSTRY REVIEW

GENERAL INFORMATION

The Mineral and Its Processing

Mica is the general name for a group of some nine different minerals, two of which, muscovite and phlogopite, are the two used by the mica industry as its raw material. All mica minerals are complex hydrous silicates with varying proportions of magnesium, potassium and aluminum, usually some iron and fluorine, and sometimes sodium, lithium, titanium, barium and manganese. Mica minerals possess some very special physical, mechanical, electrical and thermal properties. As a result, these minerals are used extensively in various fields for industrial and commercial applications.[1,2]

Mica in the form of large sheets or flakes has been an important electrical insulator because of its cleavability, flexibility and high dielectric strength. Before the invention of transistors and solid state devices, mica film was used in vacuum tubes. Currently, mica film is used in capacitors electric motors and generators. The high heat resistance of mica flakes has also prompted its use as a thermal insulator in electric appliances. Because of its special electrical and thermal properties, mica has been recognized as a strategic mineral in several industrialized countries.[1]

Mica is found widely throughout the world, (see map, page 3) but concentrations large enough and sufficiently well crystallized for processing into the valuable block mica are comparatively scarce.

Prior to 1900, the United States was the principal world producer of sheet mica. Deposits were mined in New Hampshire, North Carolina, Maine, Virginia, and South Dakota.

Mica was first produced in 1810 at the Ruggles mine in New Hampshire. Until the development of the electrical industry, specifications for mica were comparatively moderate, since its chief use then was for stove windows. The colloquial term for this product was "isinglass". As the demand for isinglass dwindled and the demand by the electrical industry grew, intensive development of mica deposits yielding higher grade sheets took place in various parts of the world. India, Brazil and Africa became important sources.[2] However, the U.S. remains the world's largest producer.

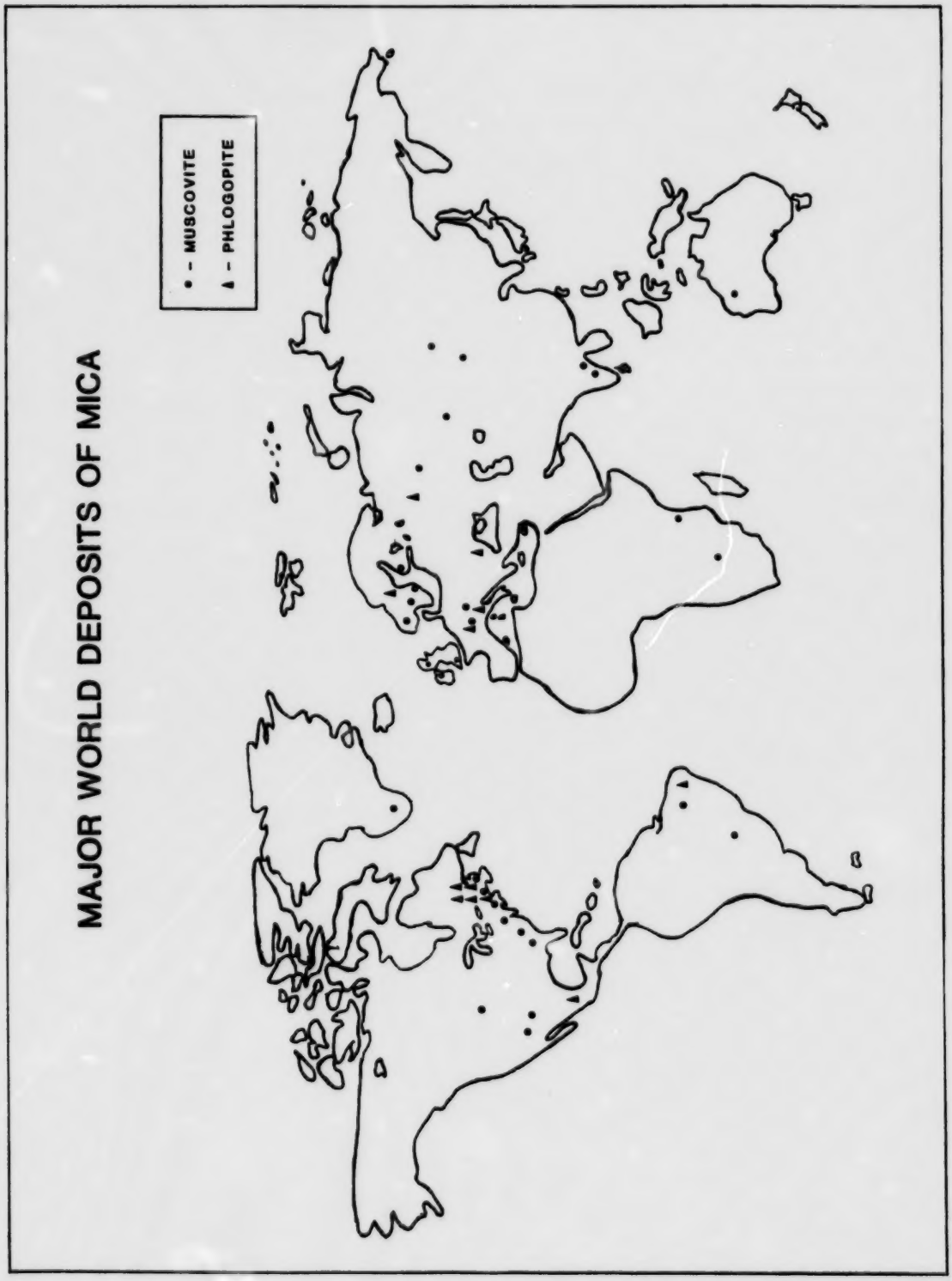
TABLE 1 - World Production
All forms (ground, flake & sheet)

(tonnes)

COUNTRY	1981 (Preliminary)	1982 (Estimated)	%
United States	226,800	183,250	63
U.S.S.R.	47,170	48,080	16
India	40,220	21,550	7
Canada	11,122	10,079	4
Republic of Korea	10,000	9,980	3
France	6,800	6,490	2
Spain	5,000	3,300	1
Brazil	4,500	4,500	2
Other	10,120	6,160	2
TOTAL	361,742	293,399	100

Source: U.S. Bureau of Mines

Because of the erratic nature of sheet mica deposits and the impossibility of predicting the profitability of a deposit, block or sheet mica is still mined by fairly primitive methods. It is general practice to "follow the vein", which means a much higher cost per tonne of rock removed, but a lower cost per tonne of mica recovered.


MAJOR WORLD DEPOSITS OF MICA
• - MUSCOVITE
▲ - PHLOGOPITE

Mica that is of poor quality for working into blocks, but is larger in size or has better crystallization than scrap, becomes the raw material for mica splittings which are extremely thin sheets or flakes (0.003 cm). In the United States and Canada, mica of this quality is marketed as "punch" or "washer" mica, where the material is punched into plain washers and simple insulating shapes for use in applications where some imperfections are not detrimental.

Mica plate is fabricated where mica is required in larger sizes than normally found in nature. It is produced by combining mica splittings with binders such as shellac, glyptol, silicone resins etc., and curing under heat and pressure.[2,5]

Dry-ground mica is produced principally by hammer mills, and is marketed in various sizes. A coarser size is used in oil well drilling fluids, while a finer size is used as a filler in gypsum board and plastic paints. There are numerous minor uses.

Wet-ground mica is produced by a batch process in mullers. After grinding, impurities (mostly quartz and feldspar) are settled out and organic impurities are floated off. After a drying operation, the mica is screened. Wet-ground mica is produced in considerably finer sizes than dry-ground (95 μm & 125 μm). Wet-ground products are being used increasingly as a filler in paint, plastics and especially for electrical insulation.[2,5]

Ground mica is made to consumer size specifications and is preferred color-free.

Sheet mica is classified into different sizes known as grades. The grade of any piece of mica is determined by the area of the largest sound rectangle which can be obtained from the original irregularly shaped piece. Quality classification is based on visual judgement (resulting in considerable variation from one producer to the next). The judgement is based on translucence, color, stains, and the presence of cracks or other physical imperfections.[2]

Mica deposits of commercial importance are located in south-central and eastern Ontario and in south-western Quebec.

At present, only one deposit in Quebec is being mined. However, there are other proven mineral deposits of phlogopite mica in Canada for possible future development.[4,5]

Currently, there is one producer of mica in Canada, Marietta Resources International Ltd. Several other companies produce mica infrequently, as a by-product of other mining operations.[5]

Recent production and trade figures are given in Table 2. The location of the major North American deposits are shown in the map on page 6.

Mica refers to a group of silicate minerals with monoclinic crystals which break off easily into thin, tough scales, varying from colorless to black.

MAJOR NORTH AMERICAN MICA DEPOSITS

TABLE 2 - Canadian Mica Production and Trade

	1978	1979	1980	1981	1982 Preliminary
Production Volume (tonnes)	5,779	11,595	10,369	11,122	10,079
Approx. Value CDN$	700,000	1,700,000	1,900,000	2,400,000	2,200,000
IMPORTS					
Ground (t)	N.A.	N.A.	2,500	3,000	2,860t
($)	N.A.	N.A.	680,000	700,035	842,000$
Block, film & sheet (t)	N.A.	N.A.	34	139	
($)	N.A.	N.A.	83,000	271,000	
Fabricated ($) Total	N.A.	N.A.	2,589,000	2,932,000	2,756,000
United States	N.A.	N.A.	2,338,000	2,598,000	2,230,000
France	N.A.	N.A.	156,000	287,000	420,000
United Kingdom	N.A.	N.A.	42,000	34,000	88,000
Other	N.A.	N.A.	53,000	13,000	28,000
EXPORTS (t)	4,334	8,696	7,777	8,342	7,559

t - tonnes
N.A. - Not Available
Source: Quebec Energy & Resource Department.

Exports of ground mica are distributed as follows:

60% United States
15% South America, Europe, Japan

There are no workable sheet mica deposits available.

The chemical composition of the two major types of mica is given below.[2,4]

TABLE 3 - Chemical Composition of Mica Group

TYPE	COMMON NAME	CHEMICAL FORMULA
Potassium Mica	Muscovite	$H_2KAl_3(SiO_4)_3$
Magnesium Mica	Phlogopite	$H_2KMg_3Al(SiO_4)_3$

Other types of mica are formed by replacing the potassium in muscovite with sodium or lithium. Impurities found in mica form stains which may consist of magnetite or hematite (iron oxide). Iron inclusions decrease the electrical insulating value.[2,4,5]

The major uses of mica are: gypsum board joint-filler cement, reinforcement in thermoplastics; asbestos substitute in cement board and pipe products and brake coatings; as an electrical and heat insulator, for circulations loss control in oil well drilling fluids; lubricant in fire extinguishers, and a reinforcing and stiffening agent in glass and phosphate bonded mica.

The American Society for Testing and Material (ASTM D351) recognizes 12 grades and quality groups of mica which are based on size and visual inspection. The grades range from OOEE to No 6 and the color from V-1 "Clear" to V-12 "Black/Red Stained", depending on color, impurities and physical defects, as indicated in Tables 4 and 5.

In addition to their elasticity, another important property of mica flakes (produced by splitting or grinding) is its "aspect ratio" (AR). This is defined as the average diameter of a flake divided by its thickness. High aspect ratio (HAR) micas have values ranging from 10 to 150. These are valued in plastics and other products where mica is used for reinforcement.

Mica is marketed as cut or uncut block, sheet, splittings and ground. Built-up mica is made by bonding splittings or ground mica with a synthetic resin and compressing at high temperatures to give uniform thickness. Because of the difficulty and cost of handling, natural mica sheet has now become almost obsolete. Built-up mica sheets are easier to handle and are of a uniform quality not found in natural mica. Synthetic micas have also been developed to replace the natural form because of the high purity that can be obtained. It can also provide higher heat resistance than natural mica.[1]

TABLE 4 - ASTM Grade Sizes of Muscovite Uncut Mica Block and Thins (ASTM D351)

ASTM GRADE SIZES	AREA OF MINIMUM RECTANGLE		MINIMUM DIMENSION OF ONE SIDE	
	in^2	equiv., cm^2	in	equiv., mm
00EE Special	100	650	4	100
0EE Special	80	520	4	100
EE Special	60	390	4	100
E Special	48	310	4	100
A-1 Special	36	235	3-1/2	89
No. 1	24	155	3	76
No. 2	15	97	2	51
No. 3	10	65	2	51
No. 4	6	40	1-1/2	38
No. 5	3	20	1	25
No. 5-1/2	2-1/4	15	7/8	22
No. 6	1	6.5	3/4	19

TABLE 5 - Classification of Visual Quality of Block Mica (ASTM D351)

CLASS	NAME
V-1	Clear
V-2	Clear & Slightly Stained
V-3	Fair Stained
V-4	Good Stained
V-5	Stained A Quality
V-5.1	Stained Al Quality
V-6	Stained B Quality
V-7	Heavy Stained
V-8	Densely Stained
V-9	Black Dotted
V-10	Black Spotted
V-11	Black Stained
V-12	Black/Red Stained

Representative physical properties are shown in Table 6.[4]

TABLE 6 - Comparison Between Muscovite and Phlogopite[4]

CHARACTERISTICS	MUSCOVITE	PHLOGOPITE
Color	Brown, Ruby & Green	Amber to dark Green
Specific Gravity	2.6 to 3.2	2.6 to 3.2
Specific Heat	0.207	0.207
Mohs Hardness	2.8 to 3.2	2.5 to 3.0
Volume Resistivity Ohms/cm^3	$2x10^{13}$ - $1x10^{17}$	Somewhat less
Modulus of Elasticity (lb/in^2)	approx. 25×10^6	approx. 25×10^6
% Water Constitution	4.5	3.0
Max. Temp. of Use	600°C	1000°C
Flexibility	less	more
Transparency	more	less
Acid Reaction	only hydro-fluoric acid	Decomposed by
Dielectric Constant	6.5 to 8.7	5.0 to 6.0
Power Factor (I/Q) for Qualities Classed as Stained or better	0.0001 - 0.0004	0.004 - 0.07

Chemical control is not important, except that in some uses of ground mica, the content of iron oxide present as an impurity must be kept very low. The presence of iron can affect its electrical insulating abilities. Industry prefers that mica be as free from color as possible. Uniformity is also important. A list of other criteria by product type is given in Table 7.

TABLE 7 - Quality Criteria for Some Uses of Mica

PRODUCT TYPE	SIZE/THICKNESS	PURITY	OTHER
Block	0.018cm thick useable area 6.45cm^2	low iron oxide	High dielectric strength, high heat resistance
Splittings	0.003cm thick useable area 4.91cm^2	"	Same
Film	0.003-0.01cm^2 thick	"	From best grades
Dry Ground	Depends on use	"	High electrical chemical and heat resistance, flexibility
e.g.: filler in paints	75 µm	"	High aspect ratio, uniform size fractions
Wet-Ground	45 µm	"	Same as dry-ground
Micronized	38 µm - 15 µm	"	Same as dry-ground

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REFERENCES

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THE NEPHELINE SYENITE INDUSTRY

ENERGY CONSERVATION IN THE INDUSTRIAL
MINERALS PROCESSING SECTOR - COMMINUTION

(Phase I - Plant Studies)

Work on this Project was conducted by
Canada Cement Lafarge Ltd.,
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APPENDIX - Industry Review
1. General Information
2. Product Characteristics
3. Quality Criteria

REFERENCES

1. INTRODUCTION

Cooperating Company:

International Minerals and Chemical Corporation

Plant Location:

Blue Mountain, Ontario

The report introduces first the company that cooperated in the study. A description follows of the comminution processes monitored during the field work at the company's plant. The measurements made and results obtained are then reported and discussed and conclusions drawn.

For readers who are not familiar with the nepheline syenite industry, an appendix entitled "Industry Review" is added. Details concerning data collection and field work, as well as other raw data or measurements, are available in working papers.

IMC Industry Group (Canada) Ltd., is controlled by International Minerals & Chemical Corporation (Canada) Ltd. (IMC).

2.1 General

IMC operates one of the two Canadian nepheline syenite mills located on Blue Mountain. The mine and plant are about 6.5 km northeast of Nephton, Ontario, at the northeast end of the Blue Mountain Intrusive.

The company began production in 1956 and now employs about 90 people. Its annual production has averaged in recent years around 240,000 tonnes representing about 40% of the North American market. In 1981, the plant was expanded to reach its present capacity of over 300,000 tonnes.

2.2 Products Marketed

The IMC product line is listed in Table 1 with corresponding particle size characteristics and applications.

"A" grade products account for the major fraction of sales with about 65% of the total. The products with the highest fineness command the highest prices. Prices range from just under $20 per short ton for the 30 mesh high fines "B" grade to over $75 for the Apex 700.

TABLE 1 - IMC Product Range

"A" GRADE PRODUCTS (Fe_2O_3 = 0.08%)	PARTICLE SIZE	APPLICATIONS
1. Apex 700	90% minus 10 µm 60% minus 5 µm 40% minus 3 µm	fillers
2. Apex 400	90% minus 20 µm 60% minus 10 µm 38% minus 5 µm	
3. Peak	96% minus 45 µm	ceramics
4. Crest	95% minus 45 µm	
5. C-3	92% minus 45 µm	
6. C-4	88% minus 45 µm	
7. Super 40 "A" Grade	100% minus 425 µm	clear glass manufacture
8. 40 Mesh "A" Grade	97% minus 425 µm	
9. 40 Mesh High Fines "A" Grade	95% minus 425 µm 23% minus 75 µm	
10. 30 Mesh "A" Grade Summit "F"	100% minus 600 µm	
11. 30 Mesh "A" Grade Summit "W"	100% minus 600 µm	
"B" GRADE PRODUCTS ($Fe_2)_3$ = 0.30%)		glass containers
1. Super 40 Mesh "B" Grade	100% minus 425 µm	
2. 30 Mesh "B" Grade Ridge	99% minus 600 µm	
3. 30 Mesh High Fines "B" Grade	100% minus 600 µm 31% minus 75 µm	
CRUDE		rockwool
1. Half Plus	100% Minus 50 mm Plus 25 mm	

3.1 Nepheline Syenite Process Flow

A summarized process flow sheet is presented in Figure I. The process flow sheet can be divided in three major areas:

- Primary ore preparation,
- "A" grade product processing,
- "B" grade product processing.

The first area, primary ore preparation, involves size reduction to minus 19 mm and classification in "A" or "B" grade storage bins. It consists of three crushing stages with a drying operation between the second and third stages. Ore classification is achieved by selective quarrying: prior to blasting, the drill cuttings are analyzed to identify the ore grade on the basis of the iron content. A sample is subjected in the lab to iron removal by means of magnetic separation and graded "A" if it assays less than 0.09% Fe_2O_3; otherwise, it is graded "B". After primary and secondary crushing, the ore is stored in piles according to its grade before going through drying and tertiary crushing. The complete drying of ore is essential before further processing.

The processing for making "A" grade products (second line in the block diagram) consists of screening, crushing, beneficiation by dust wasting and magnetic separation, glass-product screening and milling of the ceramic and filler products. After screening the tertiary crusher product, three different crushing circuits using either rolls crushers, a gyradisc or a rod mill perform a fourth

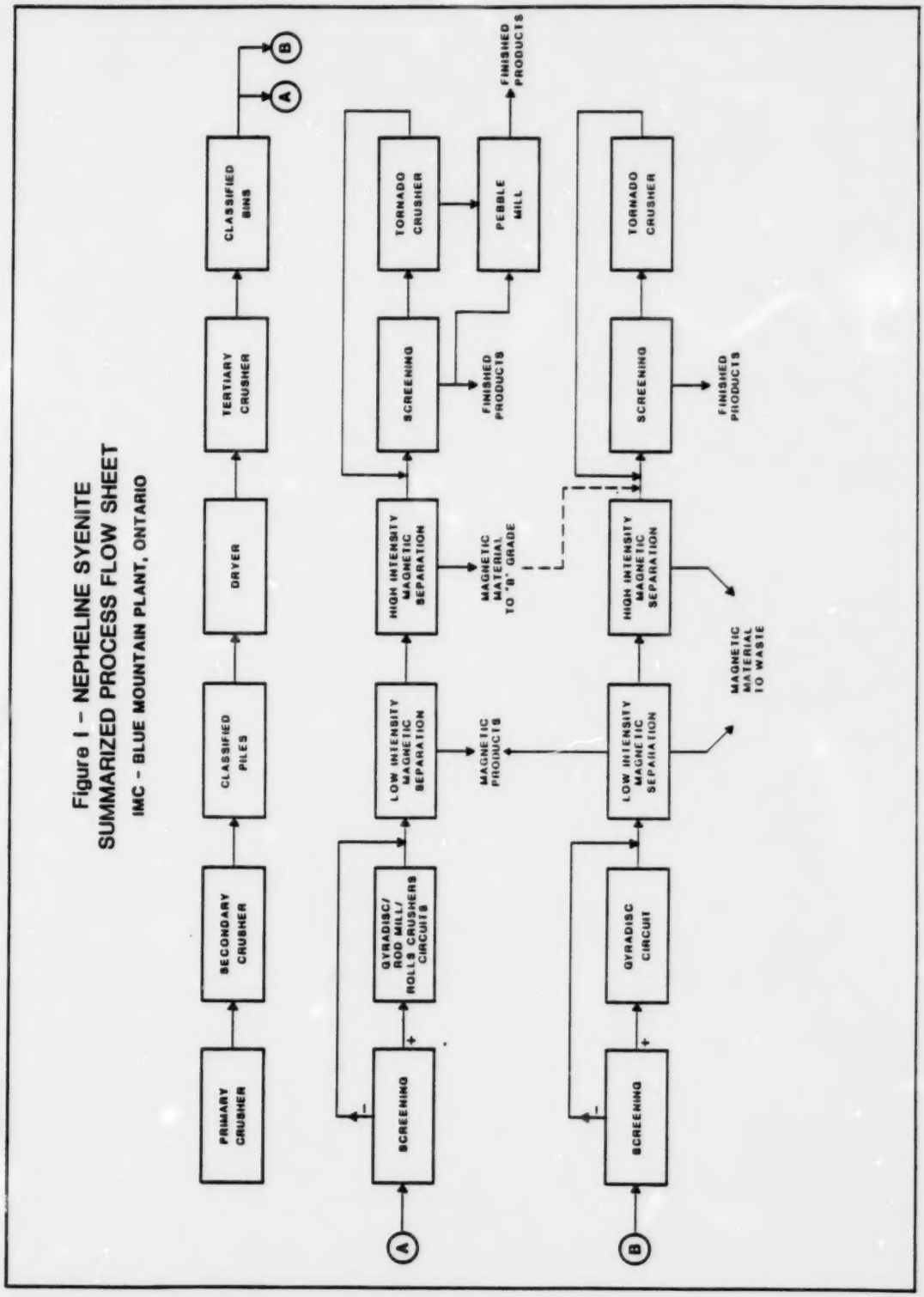

Figure I – NEPHELINE SYENITE
SUMMARIZED PROCESS FLOW SHEET
IMC – BLUE MOUNTAIN PLANT, ONTARIO

stage of crushing on the oversize. Two different magnetic separators, a low-intensity and a high-intensity type, upgrade the material before the sizing of glass-grade products. Ceramic grades, "Crest" and "Peak", are made in two pebble mill circuits, one of which is also making finer "Apex" filler grades by having a Tornado crusher to reduce coarse particles in the feed to the pebble mill.

"B" grade product processing (third line in the block diagram) resembles that of the "A" grade products. After a preliminary screening, the oversize is crushed in a gyradisc circuit before two steps of magnetic separation. A Tornado crusher reduces further the material to allow the sizing of finer glass-grade products.

3.2 Ore Crushing and Classification

The ore preparation is done in a primary crushing and classification circuit illustrated in Figure II. The equipment monitored during the survey is listed in Table 2.

The graded ore is delivered from the nearby quarry in 40-ton trucks. It is fed into a jaw crusher by a vibrating grizzly feeder that scalps the minus 110 mm fraction. The jaw crusher reduces the rock to approximately minus 170 mm. The primary crusher product joins with the grizzly undersize on a conveyor belt and is fed into a 4-ft standard cone crusher that reduces the rock to minus 75 mm. A radial stacker stockpiles the crushed product outside on piles classified according to the ore grade.

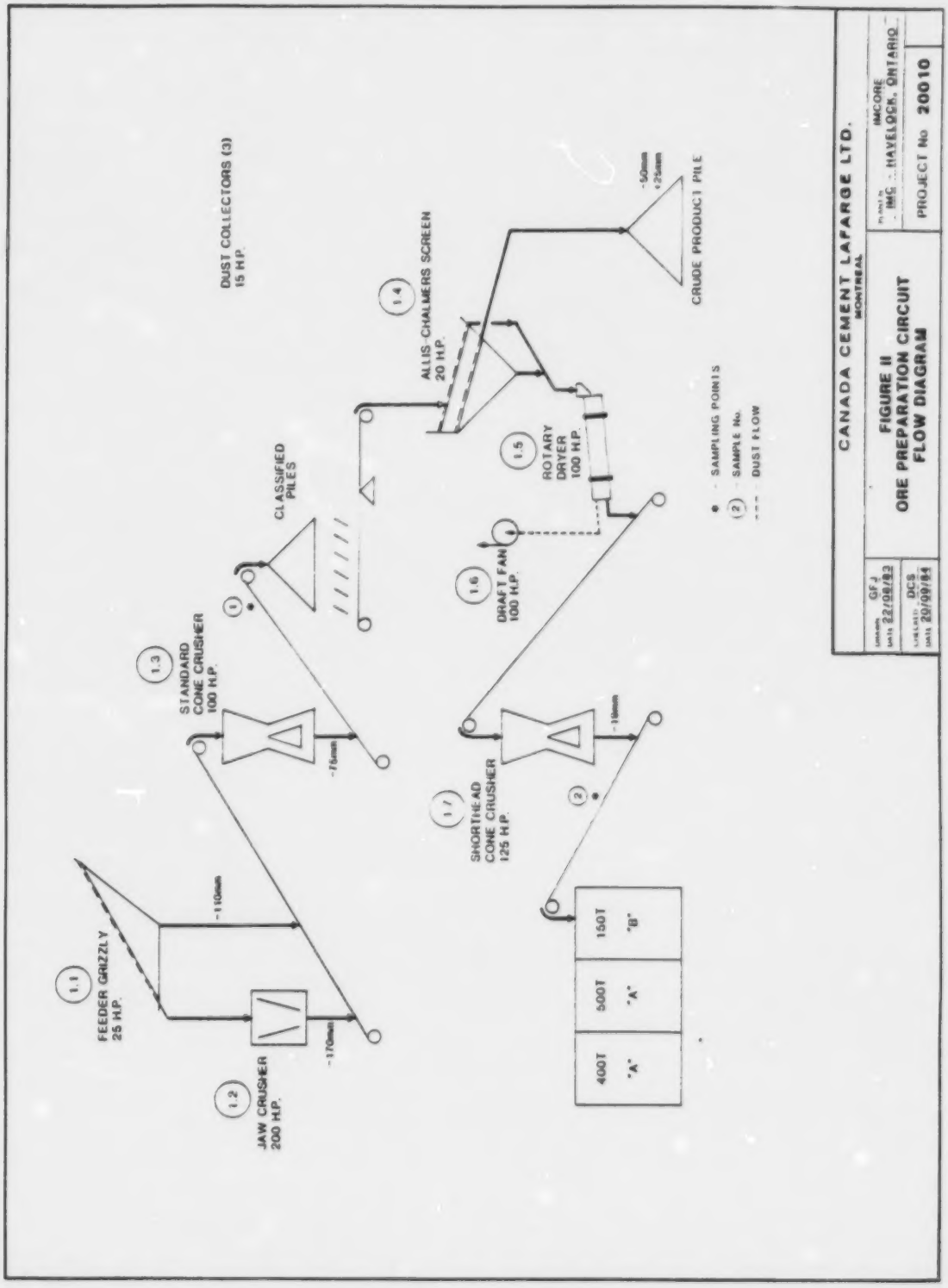
DUST COLLECTORS (3)
15 H.P.
(1.4) ALLIS-CHALMERS SCREEN
20 H.P.
CRUDE PRODUCT PILE
-50mm
+25mm
CLASSIFIED PILES
(1.5) ROTARY DRYER 100 H.P.
(1.3) STANDARD CONE CRUSHER 100 H.P.
(1.6) DRAFT FAN 100 H.P.
(1.1) FEEDER GRIZZLY 25 H.P.
-110mm
(1.2) JAW CRUSHER 200 H.P.
-170mm
-75mm
(1.7) SHORTHEAD CONE CRUSHER 125 H.P.
-19mm
400T "A"
500T "A"
150T "B"
● - SAMPLING POINTS
(2) - SAMPLE No.
--- - DUST FLOW
CANADA CEMENT LAFARGE LTD.
MONTREAL
FIGURE II
ORE PREPARATION CIRCUIT
FLOW DIAGRAM
DRAWN GFJ DATE 22/08/83
CHECKED DCS DATE 20/09/84
PLANT IMG - HAVELOCK, ONTARIO
IMCORE
PROJECT No 20010

TABLE 2 - Ore Crushing and Classification - Equipment List

EQUIPMENT		MOTOR	
No.	TYPE/MAKE/MODEL	HP	AMPS
1.1	Feeder Grizzly	25	25
1.2	Jaw Crusher	200	200
1.3	4' Standard Cone Crusher	100	100
1.4	Allis-Chalmers Screen	20	20
1.5	Rotary Dryer	100	100
1.6	Draft Fan	100	100
1.7	4 1/4' Shorthead Cone Crusher	125	125
1.8	Jaw Crusher Dust Collector	15	15
1.9	Cone Crusher Dust Collector	15	15
1.10	A.-C. Screen Dust Collector	15	15

Note: All motors are 550 volts

This part of the primary crushing circuit operates during a single 8-hour shift a day at a rate of about 200 t/h producing 1365 tonnes a day, which is sufficient to supply the milling plant with raw material for a 24-hour period. The daily production is higher when producing the crude product called "Half Plus".

An underground system reclaims the minus 75 mm ore and discharges it on to a double deck screen that separates a mid fraction (-50 mm, +25 mm), which is the crude product called "Half Plus". A weighbelt in the reclaim system regulates the flow of material through the dryer and on to a third stage of crushing at a rate in the range of 80-100 t/h. The ore moisture averages 2-3% and is removed in the drying operation. A 4½-ft shorthead cone crusher reduces the ore to minus 19 mm and the crushed product, now ready for milling, is stored in three milling plant storage silos. Two silos with a combined capacity of 800 tonnes are used for "A" grade ore and the third one with a capacity of 130 tonnes is for "B" grade ore.

This part of the primary circuit operates during two 8-hour shifts per day at an average rate of about 91 t/h.

Figure III gives vertical sections that illustrate the types of cone crushers being used in the primary crushing circuit.

3.3 Exolon* Feed Preparation

For the remaining process flow, only the "A" grade processing line will be described since the processing of "A" and "B" ores to minus 600 μm is similar.

The "A" grade product processing can be divided in three parts. The first part, identified as the Exolon feed preparation concerns a further ore size reduction through a fourth stage of crushing, in closed circuit with a battery of screens, to produce a minus 600 μm material that is suitable as feed to a first stage of magnetic separation. Five Dings machines (the trade name of a type of low-intensity magnetic drum separator) remove the highly magnetic minerals. The non-magnetic product is stored in the Exolon feed bins, ready for a second stage of magnetic separation.

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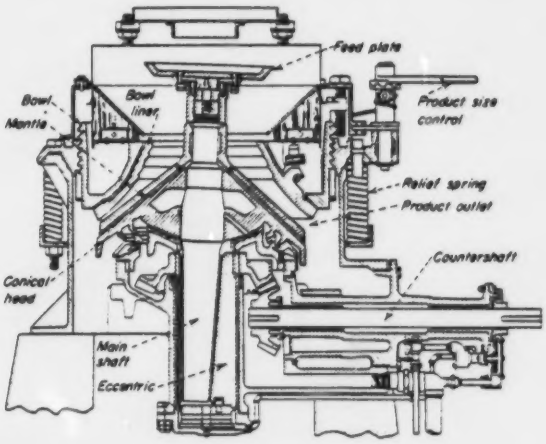
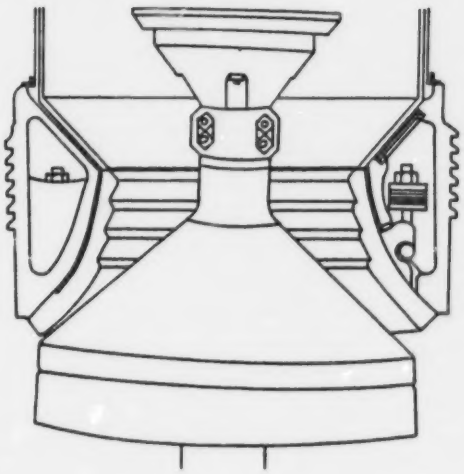
* Exolon is the trade name of a type of magnetic separator.

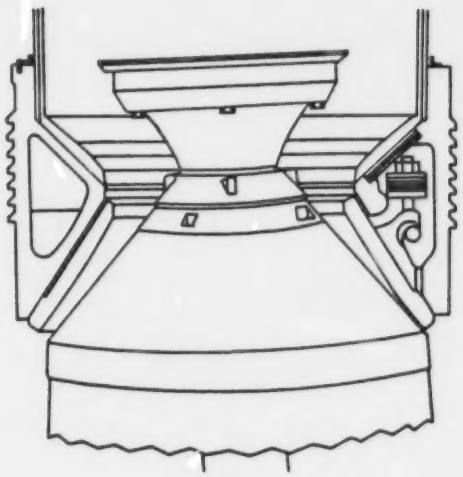
Figure III – PRIMARY CIRCUIT CONE CRUSHERS



Symons Standard Cone Crusher



Standard Crusher



Short Head Crusher

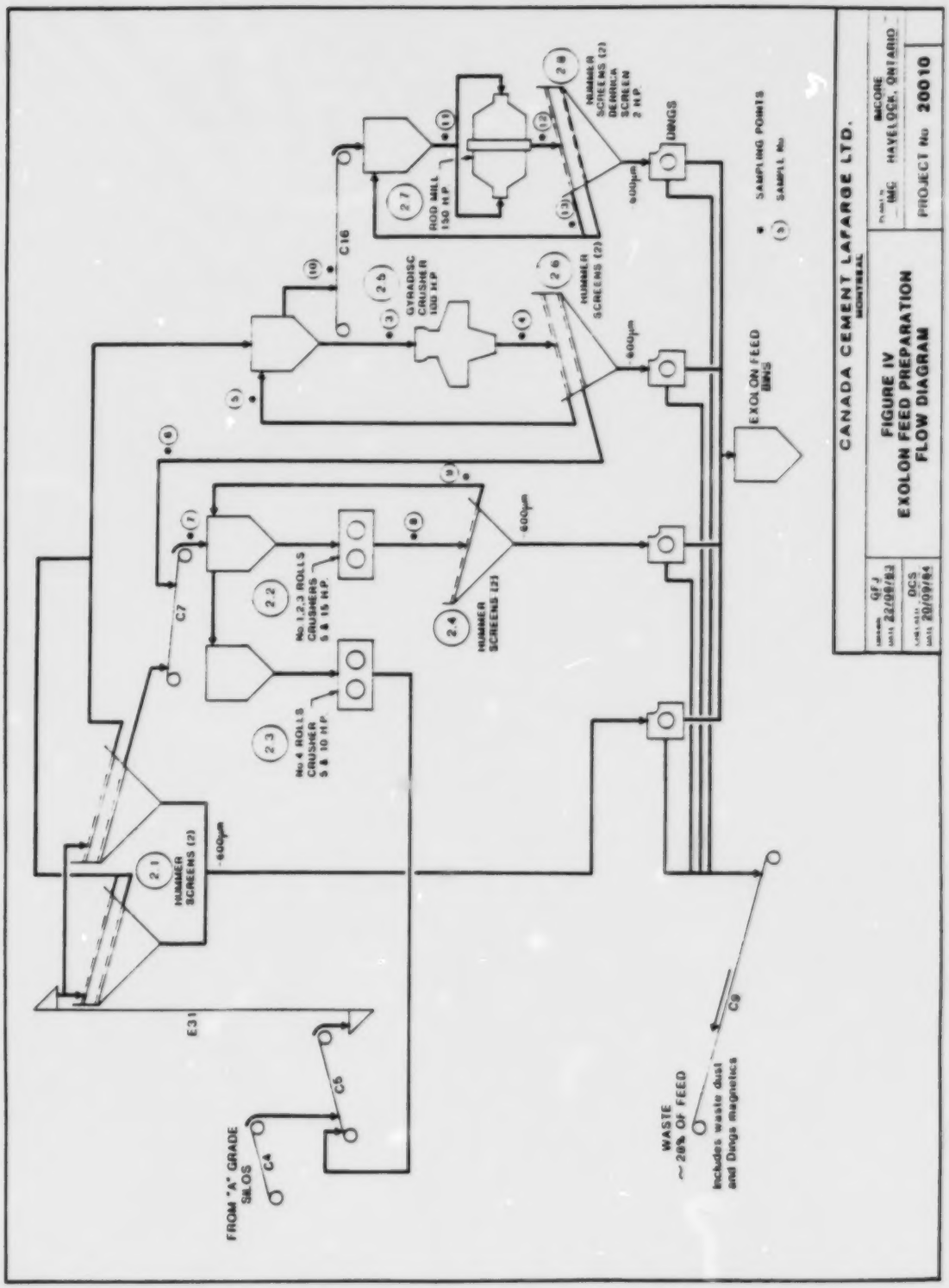
The Exolon feed preparation is illustrated in Figure IV and the equipment list is given in Table 3.

TABLE 3 - Exolon Feed Preparation - Equipment List

EQUIPMENT		MOTOR	
No.	TYPE/MAKE/MODEL	HP	AMPS
2.1	4' x 10' Hummer Screens (H1 & H2) (Electrically Vibrated)	-	-
2.2	#1, 2, 3 Rolls Crushers	5 & 15	5 & 15
2.3	#4 Rolls Crusher	5 & 10	5 & 10
2.4	4' x 10' Hummer Screens (H5 & H6)	-	-
2.5	36" Gyradisc Crusher	100	93
2.6	4' x 10' Hummer Screens (H3 & H4)	-	-
2.7	6' x 12' Rod Mill	150	137
2.8	4' x 10' Hummer Screens (H8 & H9) 3' x 10' Derrick Screen (D10)	- 2	- 2

Note: All motors are 550 volts, except Hummer screens which are 230 volts.

The fourth stage of crushing is a complex comminution operation that uses four parallel closed circuits to effect the last size reduction before beneficiation and final glass-grade sizing. Moreover, three different types of crushers are used.


CANADA CEMENT LAFARGE LTD.
MONTREAL
FIGURE IV
EXOLON FEED PREPARATION
FLOW DIAGRAM
BECORE
HAVELOCK, ONTARIO
PROJECT No 20010
DRAWN GFJ 22/09/84
CHECKED DCS 20/09/84
SAMPLING POINTS
SAMPLE No
EXOLON FEED BINS
-600µm
21 SCREENS (2)
22 No 1,2,3 ROLLS CRUSHERS 5 @ 15 HP
23 No 4 ROLLS CRUSHER 5 @ 10 HP
24 SCREENS (2)
25 GYRADISC CRUSHER 100 HP
26 SCREENS (2)
27 ROD MILL 150 HP
28 SCREENS (2) DERRICK SCREEN 2 HP
UNDERS
C7
C16
E31
C5
C4
C9
FROM "A" GRADE SILOS
WASTE ~20% OF FEED
Includes waste dust and Dings magnetics

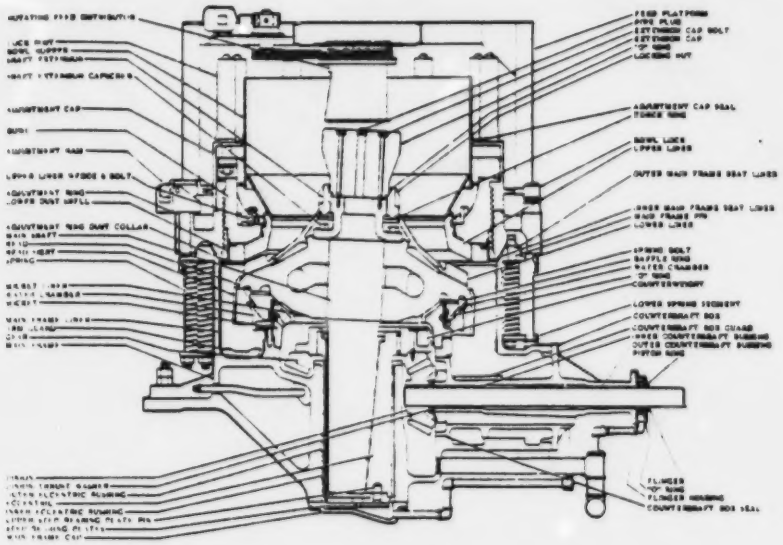
The ore from the "A" grade storage silos is screened on two double-deck Hummer screens (H1 & H2) that scalp the minus 600 μm undersize fraction which can be directly processed by one of the Dings magnetic separators. The oversize of the first deck, a plus 9.5 mm fraction, is conveyed to the gyradisc crusher feed bin; part of the material stored in that bin is then extracted to be stored in the rod mill feed bin. The mid fraction (-9.5 mm, +600 μm) on one of the screens joins the oversize and goes to the gyradisc feed bin; on the other screen, it makes up the fresh feed for the rolls crusher feed bin (#1, #2, #3 rolls crushers).

This group of three rolls crushers (No. 2.2) and the 36" gyradisc crusher (No. 2.5) effect the larger part of the fourth stage of crushing. The latter crusher reduces the coarse material while the former, the fine material. In support to these machines, the #4 rolls crusher (No. 2.3) and the rod mill (No. 2.7) are used as required.

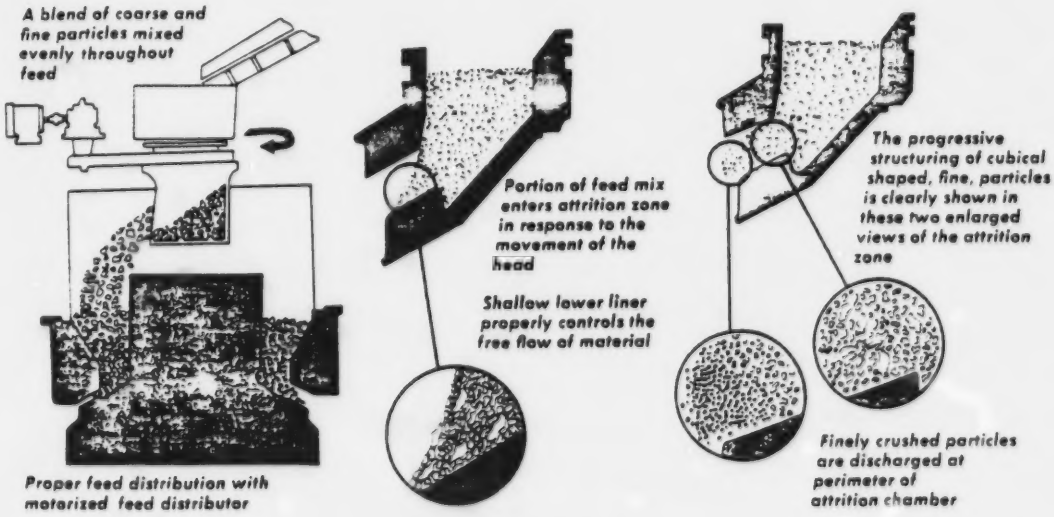
All these crushing circuits but one are closed with a set of two double-deck Hummer screens that recirculate the plus 600 μm and feed the undersize product to one of the four Dings magnetic separators. A special feature of the gyradisc screen is the fact that the intermediate size fraction (-6.3 mm, +600 μm) is diverted to the three rolls crushers circuit giving it additional feed.

Sectional views of the gyradisc crusher and of its operation are given in Figure V while the operation concept of a low-intensity magnetic drum separator is illustrated in Figure VI.

Figure V – GYRADISC CRUSHER



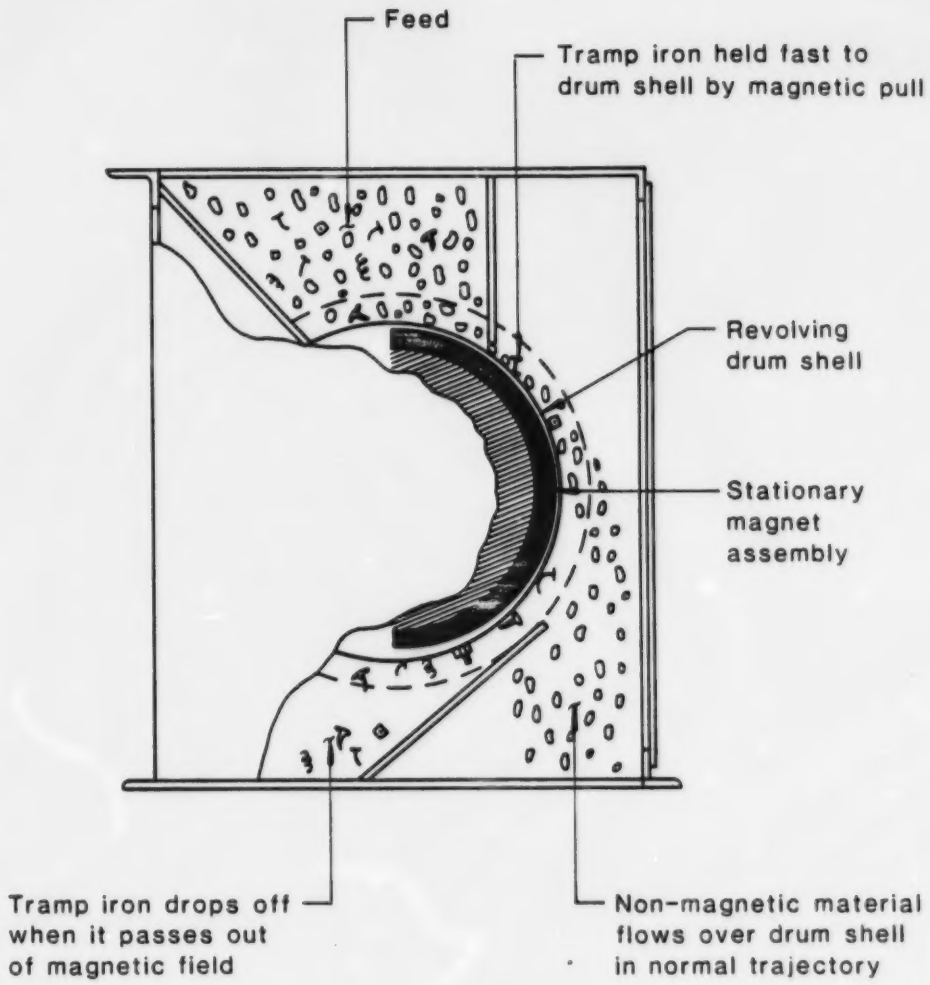
GYRADISC


A blend of coarse and fine particles mixed evenly throughout feed
Proper feed distribution with motorized feed distributor
Portion of feed mix enters attrition zone in response to the movement of the head
Shallow lower liner properly controls the free flow of material
The progressive structuring of cubical shaped, fine, particles is clearly shown in these two enlarged views of the attrition zone
Finely crushed particles are discharged at perimeter of attrition chamber

Operation

SOURCE: REXNORD INC., PROCESS MACHINERY DIVISION

Figure VI - LOW-INTENSITY MAGNETIC DRUM SEPARATOR


Feed
Tramp iron held fast to drum shell by magnetic pull
Revolving drum shell
Stationary magnet assembly
Tramp iron drops off when it passes out of magnetic field
Non-magnetic material flows over drum shell in normal trajectory

3.4 No. 2 Pebble Mill

The second part of the "A" grade product processing, identified as the No. 2 pebble mill circuit, is illustrated in Figure VII. The equipment involved in the survey is listed in Table 4.

TABLE 4 - No. 2 Pebble Mill Circuit - Equipment List

EQUIPMENT		MOTOR	
No.	TYPE/MAKE/MODEL	HP	AMPS
3.1	3' x 10' Derrick Screens (D12 & D18)	2	2
3.2	Sweco Screens (2)	3	3
3.3	#2 Pebble Mill	125	120
3.4	#2 Air Separator (Gayco)	25	25

Note: All motors are 550 volts

The non-magnetic product obtained in the first stage of magnetic separation (Dings) is fed to a bank of Exolon high-intensity magnetic separators where more magnetic minerals are removed and rejected to "B" grade product processing. The principle of operation of a high-intensity magnetic separator is illustrated schematically in Figure VIII.

The Exolon separator uses three stages of induced rolls having magnetic fields of increasing intensity, typically from 3000 to 15000 gauss. This type of magnetic separator removes successfully feebly-magnetic minerals such as biotite.

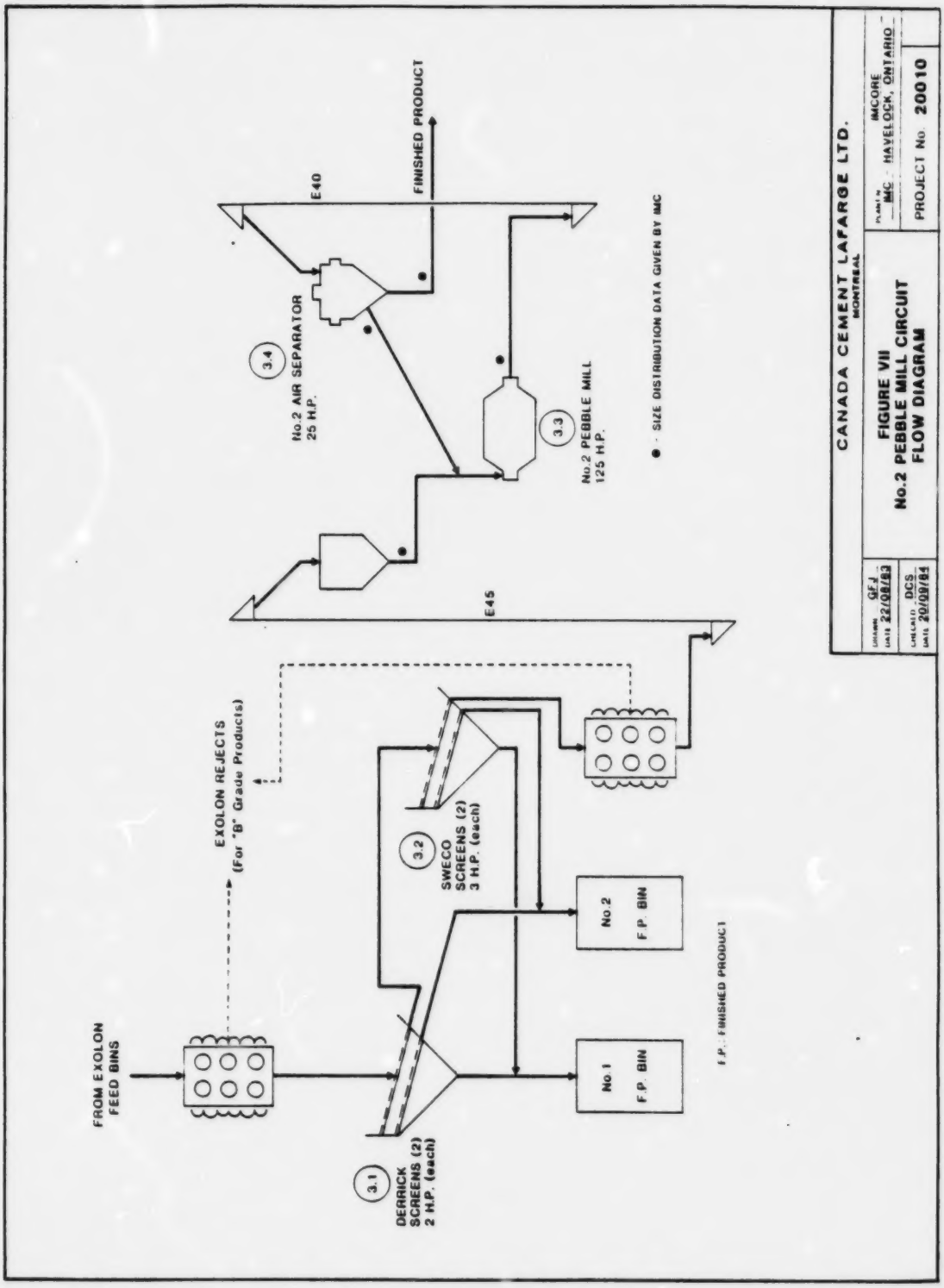
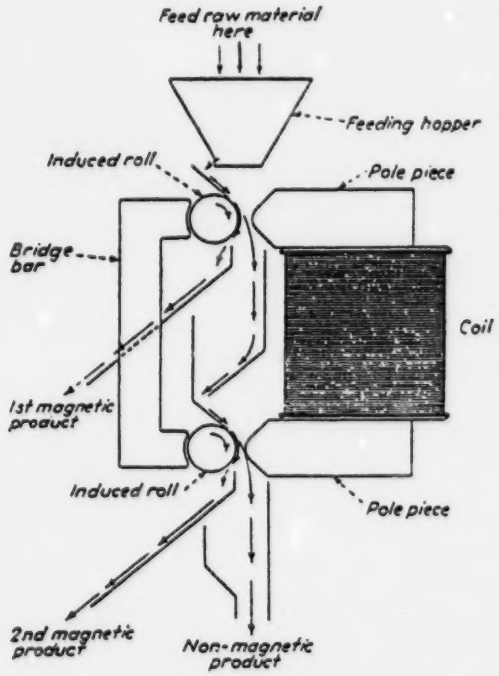

FROM EXOLON FEED BINS
EXOLON REJECTS (For "B" Grade Products)
(3.1) DERRICK SCREENS (2) 2 H.P. (each)
(3.2) SWECO SCREENS (2) 3 H.P. (each)
No. 1 F.P. BIN
No. 2 F.P. BIN
F.P. - FINISHED PRODUCT
E45
(3.3) No. 2 PEBBLE MILL 125 H.P.
(3.4) No. 2 AIR SEPARATOR 25 H.P.
E40
FINISHED PRODUCT
● - SIZE DISTRIBUTION DATA GIVEN BY IMC
CANADA CEMENT LAFARGE LTD.
MONTREAL
DRAWN GFJ DATE 22/09/83
CHECKED DCS DATE 20/09/84
FIGURE VII
No. 2 PEBBLE MILL CIRCUIT
FLOW DIAGRAM
PLANT — IMC: IMCORE HAVELOCK, ONTARIO
PROJECT No. 20010

Figure VIII - HIGH-INTENSITY MAGNETIC SEPARATOR



After this second stage of magnetic separation, the product is beneficiated to an iron content of 0.08% Fe_2O_3 and is ready for glass-grade product sizing. Two sets of two double-deck vibrating screens are used for that purpose: the first set is a pair of Derrick screens (No. 3.1) with a 355 µm top opening and a 125 µm bottom opening; the second set is a pair of Sweco screens (No. 3.2) with a 600 µm top opening and a 125 µm bottom opening. With this screen arrangement, the fines (-75 µm) are taken out and a super 40 "A" grade product can be obtained with minimal fines content.

The oversize is processed through an Exolon magnetic separator before serving as feed to the No. 2 pebble mill circuit. This circuit, which is closed by a mechanical air separator, produces the "Crest" ceramic grade having a fineness of 95% minus 45 µm.

3.5 No. 3 Pebble Mill

The third part of the "A" grade product processing, identified as the No. 3 pebble mill circuit, is illustrated in Figure IX. The equipment is listed in Table 5.

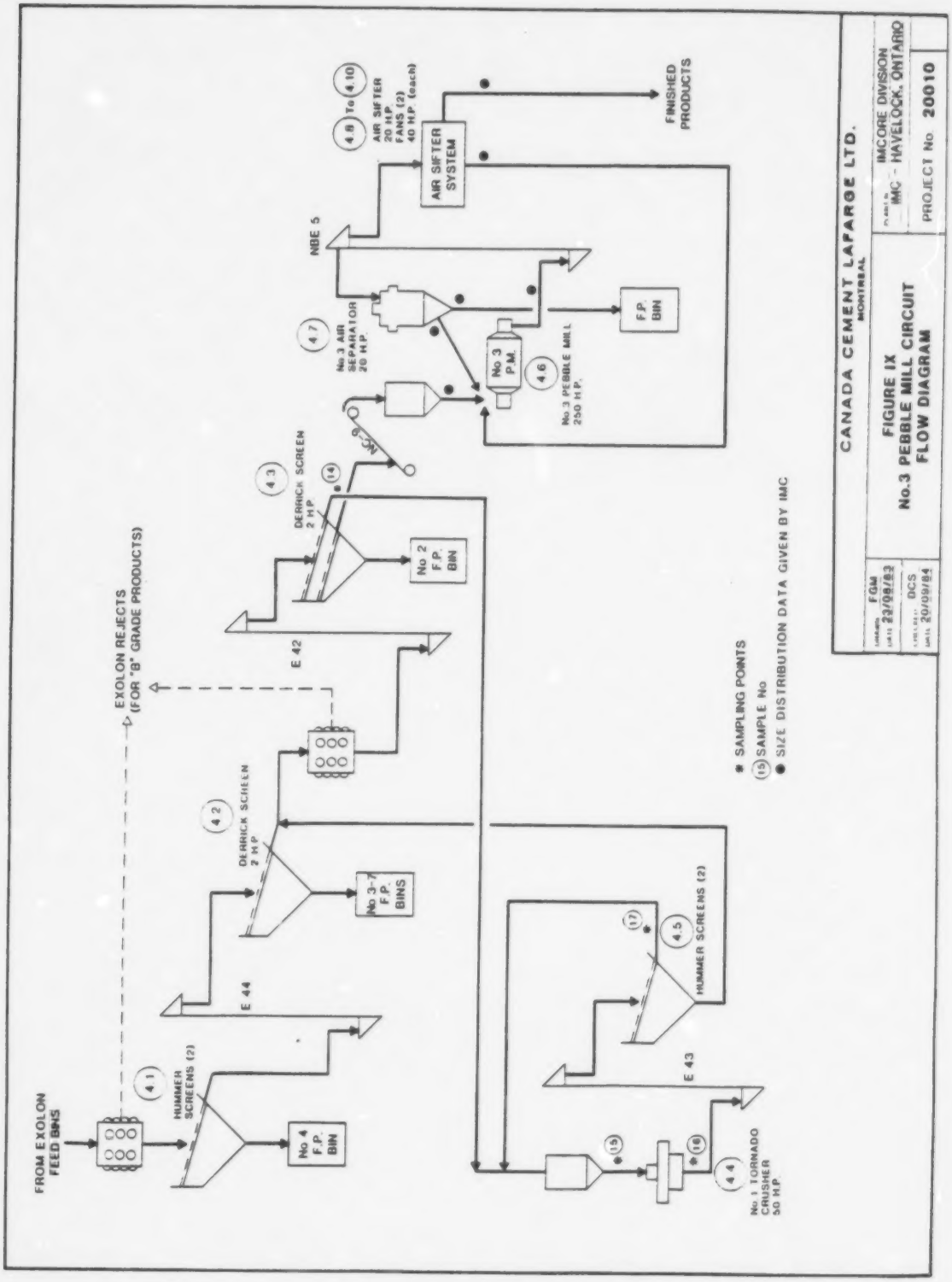

FROM EXOLON FEED BINS
(41)
HUMMER SCREENS (2)
No 4 F.P. BIN
EXOLON REJECTS (FOR "B" GRADE PRODUCTS)
(42)
DERRICK SCREEN 2 HP
No 3-1 F.P. BINS
E 44
E 42
(43)
DERRICK SCREEN 2 HP
(14)
No 2 F.P. BIN
(44)
No 1 TORNADO CRUSHER 50 HP
(15)
(16)
(17)
(45)
HUMMER SCREENS (2)
E 43
(46)
No 3 P.M.
No 3 PEBBLE MILL 250 HP.
(47)
No 3 AIR SEPARATOR 20 HP.
NBE 5
(48) To (410)
AIR SIFTER 20 HP FANS (2) 40 HP (each)
AIR SIFTER SYSTEM
F.P. BIN
FINISHED PRODUCTS
* SAMPLING POINTS
(15) SAMPLE No
● SIZE DISTRIBUTION DATA GIVEN BY IMC
CANADA CEMENT LAFARGE LTD.
MONTREAL
FIGURE IX
No.3 PEBBLE MILL CIRCUIT
FLOW DIAGRAM
IMCORE DIVISION
IMC - HAVELOCK, ONTARIO
PROJECT No. 20010
FGM 23/08/83
DCS 20/08/84

TABLE 5 - No. 3 Pebble Mill Circuit - Equipment List

EQUIPMENT		MOTOR	
No.	TYPE/MAKE/MODEL	HP	AMPS
4.1	4' x 15' Hummer Screens (H-11 to H-14)	-	-
4.2	4' x 10' Derrick Screen (D17)	2	2
4.3	3' x 10' Derrick Screen (D16)	2	2
4.4	#1 Tornado Crusher	50	48
4.5	4' x 10' Hummer Screens (H15 & H16)	-	-
4.6	#3 Pebble Mill	250	223
4.7	#3 Air Separator (Gayco)	20	21
4.8	Air Sifter	20	-
4.9	Fan #1	40	40
4.10	Fan #2	40	40

Note: All motors are 550 volts, except Hummer screens and air sifter which are 230 volts.

The processing in this pebble mill circuit resembles that of No. 2 pebble mill, except for added features such as an incorporated fine crushing circuit and an air sifter system producing an ultrafine product for filler applications.

As before, the non-magnetic product obtained in the first stage of magnetic separation proceeds to a second stage of magnetic separation. The magnetic rejects go also to "B" grade product processing.

A first screening is done on a series of four single-deck Hummer screens (No. 4.1) with a 500 µm opening. The undersizes make glass-grade products in the 500 µm range. The oversizes are pooled and screened again on a single-deck Derrick screen (No. 4.2) with a 500 µm opening. The undersize makes another glass grade product and the oversize is processed through an Exolon magnetic separator.

The non-magnetic product becomes feed for the No. 3 pebble mill circuit. A double-deck Derrick screen (No. 4.3) with a top opening of 355 µm scalps the feed: the undersize makes a 355 µm glass-grade product and the oversize is directed to the Tornado crusher circuit; only the middle fraction is conveyed to the pebble mill feed bin.

The Tornado crusher (No. 4.4) is part of a closed crushing circuit generating its circulating load with the oversize from a set of two single-deck Hummer screens (No. 4.5) with a 425 µm opening. The undersize product is added back to the feed going through the Exolon magnetic separator mentioned above and, hence screened again on the double-deck Derrick screen (No. 4.3) preparing feed for the pebble mill. This supplementary crushing and magnetic separation on coarser particles assures the quality and fineness of the No. 3 pebble mill circuit products.

The Tornado crusher operates on a centrifugal principle reducing material by impact only. It is equipped with a high-speed rotating table using blades to project particles against the wall of the cylindrical housing.

The No. 3 pebble mill is a circuit closed by a mechanical air separator that produces the "Peak" ceramic grade having a fineness of up to 98% minus 45 µm.

The No. 3 pebble mill can also deliver a feed that serves to produce the sub-sieve filler grade products, Apex 400 and Apex 700. The mill discharge, which is stored in the separator feed bin, can be partly diverted to the air sifter system (No. 4.8 to 4.10) to produce on a part-time basis these products while the "Peak" production out of the air separator is maintained.

The results of the data collection campaign are grouped under six headings:

- Ore crushing and classification
- Exolon feed preparation
- No. 2 pebble mill
- No. 3 pebble mill
- Dust collection
- Specific energy consumption by product

4.1 Ore Crushing and Classification

4.11 Electrical Measurements

A summary of the electrical measurements obtained on the ore crushing and classification circuit is presented in Table 6.

TABLE 6 - Ore Crushing and Classification

No.	EQUIPMENT	MOTOR HP	POWER OBSERVATIONS - kW		
			MAX.	MIN.	AVG.
1.1	FEEDER GRIZZLY	25	-	-	-
1.2	JAW CRUSHER	200	78	28	56
1.3	4' STANDARD CONE CRUSHER	100	45	11	28
1.4	ALLIS-CHALMERS SCREEN	20	-	-	-
1.5	ROTARY DRYER	100	54	54	54
1.6	DRAFT FAN	100	75	75	75
1.7	4½' SHORTHEAD CONE CRUSHER	125	25	20	24
1.8	JAW CRUSHER DUST COLLECTOR	15	10	10	10
1.9	CONE CRUSHERS DUST COLLECTOR	15	10	10	10
1.10	A.-C. SCREEN DUST COLLECTOR	15	9	9	9

The power level observations for the three crushers of the circuit were obtained by recording each motor power demand. For other equipment having stable electric loads, the Amprobe meter or an ammeter was used. The Allis-Chalmers screen was not operational and the feeder was not monitored (the latter is usually a small electric load).

From the examination of these measurements the following comments can be made:

- The loading of the crushers is low: compared to installed power of 317 kW (425 HP), the average power demand totals only 108 kW, or 34%; Table 7 presents the electric loading of the crusher motors.

TABLE 7 - Crusher Motor Load

CRUSHER	% NOMINAL POWER
Primary Secondary Tertiary	38 38 26
Average	34

- The power demand of the auxiliary equipment, particularly the dryer and its draft fan, is high at 158 kW and represents about one and a half times that of the comminution equipment.

4.12 Flowrates

The crushing circuit being made up of two parts, two flowrates must be considered to determine the average hourly production rate needed for specific power consumption calculations.

The average flowrate through the first part of the circuit consisting of the primary and secondary crushers is estimated in the following manner. In an 8-hour shift, only 7 hours are considered operational, giving a daily production of 1360 tonnes, an average of 194 t/h and a utilization factor of about 90%. This part of the circuit operates intermittently due to the random arrival rate of trucks feeding the primary crusher; this causes time when crushers run idle.

The second part of the circuit, comprising the dryer and tertiary crusher, operates continuously during two 8-hour shifts of which 15 hours are considered operational. Thus, the average production rate is 91 t/h.

4.13 Size Distributions

The primary crusher feed size distribution was minus 900 mm, plus 50 mm and mainly minus 450 mm, plus 150 mm.

The primary product size distribution was estimated to be minus 175 mm with the bulk in the 50 mm x 100 mm range.

The distributions for the secondary and tertiary crushers products are given in Table 8.

TABLE 8 - Ore Crushing Size Distributions

SAMPLE # mm	#1 SECONDARY CRUSHER PRODUCT (% Passing)	#2 TERTIARY CRUSHER PRODUCT (% Passing)
100	100	
75	95.7	
50	87.5	
38.1	73.0	
31.5	-	100
25.0	56.8	98.7
19.0	48.6	94.2
12.5	38.0	81.3
9.5	32.7	68.3
4.75	24.5	50.6
2.36	20.8	42.0
1.18	16.6	33.5
0.600	11.1	21.1
0.300	7.1	20.9
0.150	4.2	4.3

The secondary crusher product distribution was adjusted to account for a bias caused by the small sample size (24 kg) (see working papers).

At the time of sampling, the Allis-Chalmers screen was not in operation to remove the minus 50 mm, plus 25 mm fraction ("Half Plus" crude product), which means the secondary crusher product distribution is also the tertiary crusher feed distribution.

4.14 Grindability Testing

The grindability testing by both the Hardgrove and Bond test procedures was performed on the secondary crusher product.

The Hardgrove Index (HGI) found on this nepheline syenite ore is 41. The Bond Index was found to be 13.85 kWh/tonne, which is similar to the Bond Index calculated from the Hardgrove Index (14.82 kWh/ton).

These results suggest that this ore is difficult to grind and equivalent to very hard cement clinkers and average quartz. It also implies that this mineral is hard and probably abrasive, but not necessarily that it is difficult to crush.

4.15 Specific Energy Consumption

The procedure used to calculate the specific consumption consists simply in adding up the average power demand of each motor and dividing this total power demand by the average production rate. As the ore crushing circuit is made up of two parts, each with a particular production rate, the specific consumption for the circuit is obtained by adding the specific consumptions calculated for each of the two parts.

For the primary and secondary crushers, the total power demand amounts to 104 kW, including the dust collectors (Equipment No.1.8 and 1.9). Dividing by 194 t/h a specific consumption of 0.535 kWh/t is found. By taking only the crushers' motors power demand (84 kW), a specific consumption of 0.432 kWh/t is determined for comminution alone.

The same calculations are made for the second part comprising the dryer and tertiary crusher. Total power demand amounts to 162 kW, the average production rate is 91 t/h and a specific consumption of 1.79 kWh/t is found. The consumption for comminution alone represents only 0.265 kWh/t.

The following table gives a summary of these results.

TABLE 9 - Ore Crushing and Classification
Detailed Specific Power Consumption

		kWh/tonne	%
Primary and Secondary Crushers	Crushing	0.43	81
	Auxiliaries	0.10	19
	Total	0.53	100
Dryer and Tertiary Crusher	Crushing	0.26	15
	Auxiliaries	1.53	85
	Total	1.79	100

Table 10 gives the results for the complete circuit.

TABLE 10 - Ore Crushing and Classification
Specific Power Consumption

	kWh/tonne	%
Crushing	0.70	30
Auxiliaries	1.62	70
Total	2.32	100

The results demonstrate two facts already mentioned in 4.11:

- The low consumption for comminution alone shown by the low value of specific consumption for crushing.

- The high total consumption caused by the dryer and, particularly, the draft fan whose power demand

(75 kW) appears to be disproportionate to the moisture content of the rock (2-3% H_2O). This situation is highlighted in Table 9 by the low percentage of comminution consumption for the second part of the crushing circuit.

4.2 Exolon Feed Preparation

4.21 Electrical Measurements

The electrical measurements obtained in the Exolon feed preparation circuit are presented in Table 11.

TABLE 11 - Exolon Feed Preparation

No.	EQUIPMENT	MOTOR HP	POWER OBSERVATIONS - kW		
			MAX.	MIN.	AVG.
2.1	4' x 10' HUMMER SCREENS (2)	-	1.6	1.6	1.6
2.2	#1, 2, 3 ROLLS CRUSHERS	3 x 5	8.3	8.3	8.3
		3 x 15	29	29	29
2.3	#4 ROLLS CRUSHER	5	1.7	1.7	1.7
		10	5.0	5.0	5.0
2.4	4' x 10' HUMMER SCREENS (2)	-	1.6	1.6	1.6
2.5	36" GYRADISC CRUSHER	100	44	44	44
2.6	4' x 10' HUMMER SCREENS (2)	-	1.6	1.6	1.6
2.7	6' x 12' ROD MILL	150	74	74	74
2.8	4' x 10' HUMMER SCREENS (2)	-	1.6	1.6	1.6
	3' x 10' DERRICK SCREEN	2	0.8	0.8	0.8

The Hummer screens are electrically-vibrated and operated on 230 volt power supply; their power demand has been calculated on the basis of 4 amps and a 0.85 power factor giving 0.8 kW on each screen. The rolls crushers power demand (No. 2.2) is expressed as a combined demand for one motor type. The power consumption of the Dings magnetic separators was not monitored but is considered to be low.

These measurements indicate that the comminution equipment, with a power demand of 162 kW, takes 96% of the total demand. The rod mill comes out clearly as the largest consumer. The total of all rolls crushers at 44 kW equals the gyradisc demand.

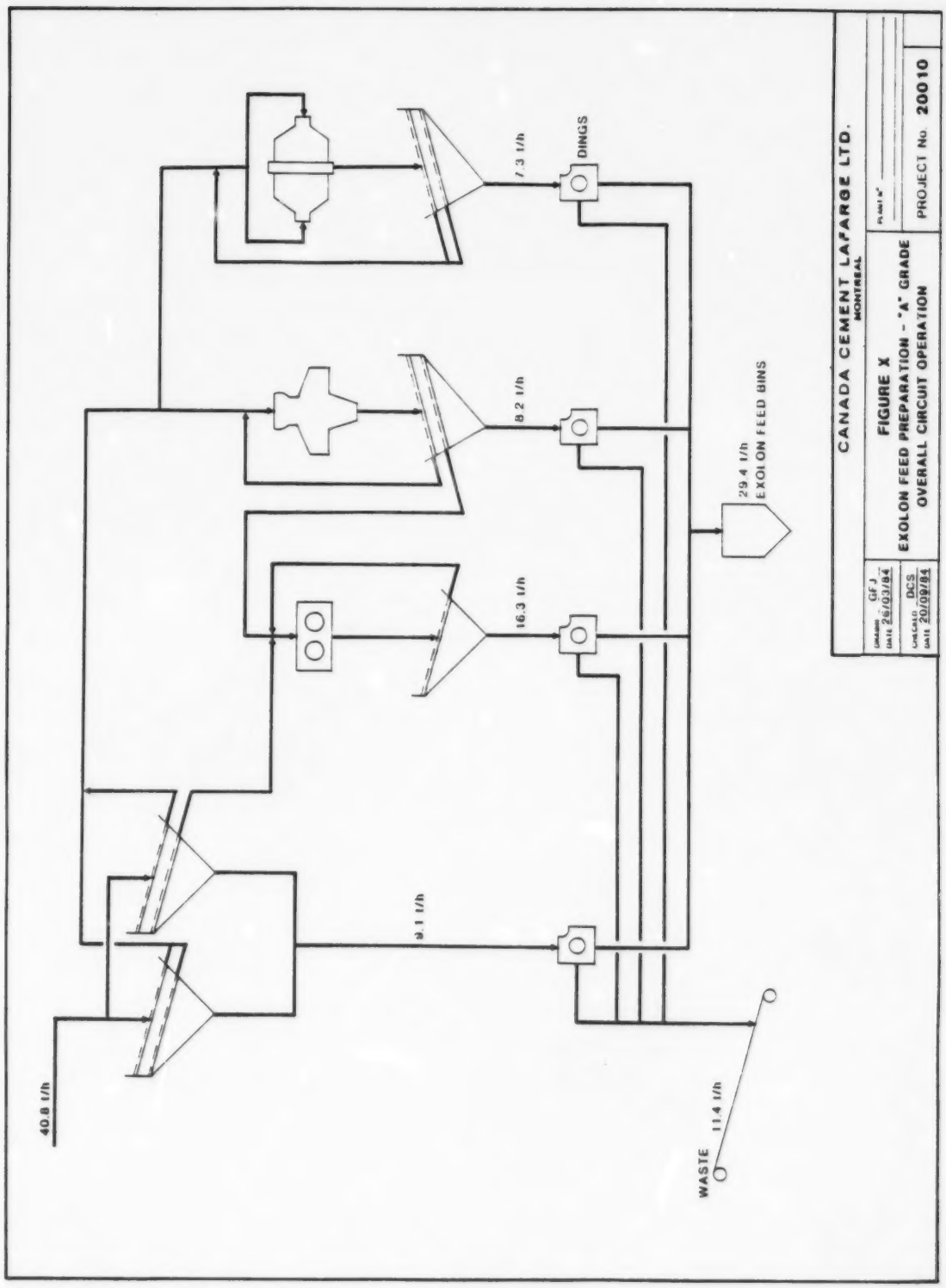
4.22 Flowrates

No flowrate measurements were made during the field work period. The flowrates needed for computing specific energy consumptions are based on plant records and operating experience.

The circuit processes 980 tonnes per day of crushed ore extracted from the "A" grade storage silos. This is equivalent to 40.8 t/h. A typical circuit operation is illustrated in the flow diagram in Figure X. Production rates are given for each stream of minus 600 μm material feeding the Dings separators. On this flow diagram, the #4 rolls crusher is neglected (its production is rated at 3.6 t/h) as it produces a circulating load which is mixed back into the incoming feed to the circuit. The recovery of non-magnetic material after the Dings separators is assumed to be 72%, which translates into a production rate of 29.4 t/h of Exolon feed.

4.23 Size Distributions

The size distributions obtained from the screen analysis of the 11 samples taken in the circuit are presented in Tables 12-14.


7.3 t/h
DINGS
8.2 t/h
29.4 t/h
EXOLON FEED BINS
16.3 t/h
9.1 t/h
40.8 t/h
WASTE 11.4 t/h
CANADA CEMENT LAFARGE LTD.
MONTREAL
FIGURE X
EXOLON FEED PREPARATION - "A" GRADE
OVERALL CIRCUIT OPERATION
DRAWN GFJ DATE 26/03/84
CHECKED DCS DATE 29/09/84
PROJECT No. 20010

The feed extracted from the "A" grade silos is screened to scalp off the minus 600 μm fraction which is directly processed by a Dings separator. The tertiary crusher product distribution (Table 8) confirms the flowrate for this stream (9.1 t/h).

Secondly, the size distributions for the flows around the gyradisc crusher are given in Table 12.

TABLE 12 - Gyradisc Crusher Size Distributions

(% Passing)

SAMPLE # mm	#3 GYRADISC FEED BIN DISCHARGE	#4 GYRADISC PRODUCT	#5 RECIRCULATION TO GYRADISC FEED BIN	#6 GYRADISC PRODUCT TO ROLLS FEED SUPPLY
25.0	100	100	100	
19.0	97.2	98.9	99.2	
12.5	90.1	90.6	89.4	
9.5	84.1	77.9	67.4	100
4.75	74.1	54.6	16.3	99.4
2.36	64.7	41.7	3.1	87.8
1.18	45.2	31.9	1.2	71.4
0.600	12.3	17.5	0.6	39.8
0.300	2.5	7.8	0.3	19.0
0.150	0.5	1.6	0.2	8.2

An examination of the data brings out an anomaly: the gyradisc product (#4) appears to be coarser than the feed bin discharge (#3), specifically in the 1.18 to 12.5 mm range. This situation can only be due to a non-representative sample. The high fineness of the gyradisc feed is noteworthy and adds to the preceding remark: for instance, the minus 600 μm in the product should be more than double the one in the feed, according to information

from the manufacturer, i.e., in the order of 30-35% instead of the 17.5% reported.

The two other distributions (#5 and #6) give an indication of the screening performance and the amount of recirculation and feed supplied to the rolls feed bin. By observing the separation size and comparing with previous distributions (#2 and #3), the flow through the gyradisc is estimated at about 29 t/h, the recirculating flow (oversize) at 10 t/h and the supply flow to rolls (mid-size) at 10.9 t/h.

The size distributions concerning the roll crushers are given in Table 13. The rolls product distribution (#8) exhibits the same phenomenon as in the case of the gyradisc: it also appears to be coarser than the rolls feed supply (#7), especially in the range of minus 1.18 mm and less. This fact could be due again to a non-representative sample collected from the top of the screen deck; the minus 600 μm in the product should be in the range of 40-60% from a material balance viewpoint, if the production rate (16.3 t/h) and screening capacity (32-36 t/h) are considered. In fact, examination of the recirculation distribution seems to indicate a flow through the rolls crushers of about 30 t/h with a recirculation of 13.6 t/h representing 45% of the crushers flow. The difference (55%) would be represented by the production flowrate (16.3 t/h). This hypothesis would confirm a 60% minus 600 μm in the rolls product distribution.

TABLE 13 - Roll Crushers Size Distributions

(% Passing)

SAMPLE # mm	#7 ROLLS FEED SUPPLY	#8 ROLLS PRODUCT	#9 RECIRCULATION TO ROLLS FEED BIN
12.5	100		
9.5	99.5	100	100
4.75	97.0	99.4	99.3
2.36	85.2	87.2	83.0
1.18	65.4	62.3	52.3
0.600	30.9	25.9	11.4
0.300	13.7	10.1	1.7
0.150	5.8	4.2	0.3

The rolls feed supply distribution (#7) is a composite of a part of the mid-size from the scalping screens (see Figure IV) and of the mid-size screened from the gyradisc product (distribution #6).

The size distributions relating to the rod mill are given in Table 14.

TABLE 14 - Rod Mill Size Distributions

(% Passing)

SAMPLE # mm	#10 GYRADISC FEED BIN SUPPLY TO ROD MILL FEED BIN	#11 ROD MILL FEED BIN DISCHARGE	#12 ROD MILL PRODUCT	#13 RECIRCULATION TO ROD MILL FEED BIN
25.0	100			
19.0	95.8			
12.5	80.3	100		
9.5	58.4	99.0	100	100
4.75	28.1	94.7	99.9	98.9
2.36	15.5	89.8	99.3	96.9
1.18	6.9	77.9	91.4	85.1
0.600	1.5	23.4	38.0	14.3
0.300	0.5	7.4	19.1	1.4
0.150	0.2	2.1	10.4	0.4

The distribution (#10) of the supply to rod mill from the gyradisc feed bin appears surprisingly coarse when compared to both feed bin discharge and recirculation distributions (#11 and #13). It can probably be explained by bin segregation whereby larger particles may lie preferentially at the bin periphery (pile effect) while the finer material stays in the center. Distribution #10, from a sample taken on the belt conveyor reclaiming material from the side of the gyradisc feed bin, would illustrate the occurrence of this phenomenon from time to time. Furthermore, the segregation phenomenon is also present in the rod mill feed bin as demonstrated by comparison of both feed bin discharge and recirculation distributions (#11 and #13) with that of feed supply (#10). The coarser size of the latter is not represented in the distribution of the feed bin discharge (mill feed), indicating probably that, at the time of sampling, larger particles were falling to the bin periphery instead of being funnelled into the discharge.

Comparison of the recirculation distribution (#13) with that of feed bin discharge (#11), although the latter may be highly affected by segregation, points to a high circulating load, in the order of two to three times the production rate. A similar comparison between recirculation (#13) and rod mill product (#12) leads to the same observation for the rod mill. Flow would be in the order of 27 t/h with about 70% represented by recirculation (20 t/h).

4.24 Specific Energy Consumption

The three comminution machines are compared to show their relative impact on power consumption. The circuit specific energy consumption is established on the basis of beneficiated ore (Exolon feed). The data does not include the consumption of Dings magnetic separators.

Table 15 gives the power consumption data for each of the three crushing circuits by using average power observations and production rates. The data indicates the large differences in specific consumption that exists between these crushing circuits, particularly in the case of the rod mill. No comment can be made in regard to specific consumption as a function of product quality, which could be defined as maximum production having minimum amount of minus 150 μm particles (high-quality glass grade), because the crusher product size distributions have been found inaccurate.

TABLE 15 - Fourth Stage Crushing
Specific Power Consumption

		kWh/tonne	%
Rolls Crushers (#1, 2, 3)	Crushing	2.28	96
	Auxiliaries	0.10	4
	Total	2.38	100
Gyradisc Crusher	Crushing	5.39	96
	Auxiliaries	0.20	4
	Total	5.59	100
Rod Mill	Crushing	10.2	97
	Auxiliaries	0.3	3
	Total	10.5	100

The average specific power consumption for the fourth stage of crushing is given in Table 16.

TABLE 16 - Exolon Feed Preparation
Specific Power Consumption

	kWh/tonne	%
Crushing	5.51	96
Auxiliaries	0.25	4
Total	5.76	100

4.3 No. 2 Pebble Mill

4.31 Electrical Measurements

The electrical measurements obtained in the No. 2 pebble mill circuit are presented in Table 17.

TABLE 17 - No. 2 Pebble Mill

		MOTOR HP	POWER OBSERVATIONS - kW		
No.	EQUIPMENT		MAX.	MIN.	AVG.
3.1	3' x 10' DERRICK SCREENS (2)	2	1.6	1.6	1.6
3.2	SWECO SCREENS (2)	2 x 3	-	-	-
3.3	#2 PEBBLE MILL	125	75	75	75
3.4	#2 SEPARATOR	25	8	8	8

The No. 2 pebble mill drive is only loaded at 80% of nominal power. No measurement was taken on the Sweco screens. The power demand for the Exolon magnetic separator was not monitored but is considered to be low (estimated power demand would be 0.6 kW per unit).

4.32 Flowrates

The production rate established for Exolon feed preparation is assumed to be divided among the Exolon units in a proportion that directs close to one third of the flow rate to the No. 2 pebble mill circuit and two thirds to the No. 3 pebble mill circuit. The split is thus 9.3 t/h and 20.1 t/h, respectively.

The recovery of beneficiated material from the Exolon separators is estimated to be 90% and, as the rejects are not lost but downgraded to "B" products, this factor does not reduce the production rate in regard to glass-grade products.

Production rate data used to compute specific power consumptions was supplied by IMC.

4.33 Size Distributions

The size distributions around the No. 2 pebble mill, which were supplied by plant staff, are shown in Table 18. Few comments need to be made, except to note that the finished product has a 95% passing 45 μm, which is the Crest grade specification. Other ceramic grades, namely C-3 and C-4, have a lower 45 μm specification, 92% and 88% passing, respectively.

TABLE 18 - No. 2 Pebble Mill Circuit
Size Distributions (% Passing)

µm	Fresh Feed	Mill Discharge	Separator Rejects	Finished Product
850	100	-	-	-
600	96.4	-	-	-
500	66.1	-	-	-
425	35.8	-	-	-
300	3.8	-	-	-
250	1.5	-	-	-
106	-	100	100	-
75	-	98.0	97.0	100
45	-	80.8	58.9	99.7
30	-	55.2	19.5	88.6
20	-	36.3	6.0	66.8
10	-	20.5	4.0	38.0
6	-	14.7	3.7	25.0
2	-	9.8	3.5	11.8

4.34 Specific Energy Consumption

The specific energy consumption is computed on the basis of the power demand of both pebble mill and air separator (Equipment Nos. 3.3 & 3.4). The resulting specific consumption is given in Table 19.

TABLE 19 - No. 2 Pebble Mill
Specific Power Consumption

	kWh/tonne	%
Grinding	35.9	90
Auxiliaries	3.9	10
Total	39.8	100

This performance can be compared to the reference reported in Taggart's Handbook of Mineral Dressing for a conical mill (8' x 48") grinding a nepheline syenite product to

95% minus 45 µm at 1 t/h using 85 HP (separator included): the specific consumption amounted in that case to 63.3 kWh/tonne, which is considerably more than what is reported in the above table.

4.4 No. 3 Pebble Mill

4.41 Electrical Measurements

The electrical measurements obtained in the No. 3 pebble mill circuit are presented in Table 20.

The No. 3 pebble mill is run fully loaded at 98% of nominal power. The circuit includes a closed-circuit crusher, the Tornado crusher, well loaded at 75% of nominal power and an air sifter system, lightly loaded at 43% of nominal power.

TABLE 20 - No. 3 Pebble Mill

No.	EQUIPMENT	MOTOR HP	POWER OBSERVATIONS - kW		
			MAX.	MIN.	AVG.
4.1	4' x 15' Hummer Screens (4)	-	3.2	3.2	3.2
4.2	4' x 10' Derrick Screen	2	0.8	0.8	0.8
4.3	3' x 10' Derrick Screen	2	0.8	0.8	0.8
4.4	#1 Tornado Crusher	50	28	28	28
4.5	4' x 10' Hummer Screens (2)	-	1.6	1.6	1.6
4.6	#3 Pebble Mill	250	183	183	183
4.7	#3 Air Separator	20	7	7	7
4.8	Air Sifter	20	6	6	6
4.9	Fan #1	40	12	12	12
4.10	Fan #2	40	15	15	15

4.42 Flowrates

Production rate data was supplied by IMC.

4.43 Size Distributions

The size distributions concerning the Tornado crusher operation are given in Table 21.

TABLE 21 - Tornado Crusher Size Distributions

(% Passing)

SAMPLE # / mm	#14 TORNADO MILL FEED SUPPLY	#15 TORNADO MILL FEED BIN DISCHARGE	#16 TORNADO MILL PRODUCT	#17 RECIRCULATION TO TORNADO FEED BIN
4.75	100			
2.36	99.9		100	100
1.18	99.4	100	99.9	99.9
0.600	70.9	84.5	92.9	82.2
0.300	8.7	10.0	33.1	8.2
0.150	1.5	1.4	14.2	1.6

Both feed supply and recirculation distributions (#14 and #17) appear to be clearly the result of screening with the same screen aperture (425 μm), somewhat above the 300 μm reported in the screen analysis. The comparison of these with the feed bin discharge distribution (#15) points to a greater resemblance with the recirculation distribution, indicating probably a high circulating load. The Tornado mill product distribution (#16), when compared to feed bin discharge, reveals a good amount of comminution work being performed.

The size distributions of the pebble mill system are shown in Table 22. The finished product (Peak) from the air separator has better than the specified 96% minus 45 μm.

TABLE 22 - No. 3 Pebble Mill Circuit
Size Distributions (% Passing)

µm	Fresh Feed	Mill Discharge	Separator Rejects	Finished Product
850	100	-	-	-
600	96.5	-	-	-
500	72.6	-	-	-
425	47.1	-	-	-
300	14.4	-	-	-
250	8.9	-	-	-
106	-	100	100	-
75	-	98.0	97.0	100
45	-	91.5	84.0	98.0
30	-	73.2	62.2	93.1
20	-	50.4	41.3	81.3
10	-	28.3	22.8	55.0
6	-	20.0	16.7	39.3
2	-	12.0	11.0	19.2

4.44 Specific Energy Consumption

Separate specific consumptions are computed for the Tornado crusher, the pebble mill and the air sifter system on the basis of average power observations (Table 20) and average production rates. The power consumption of screens (No. 4.1, 4.2 and 4.3) ahead of pebble mill feed bin is not included in these results. The air sifter system power demand is assumed to remain constant whatever product is made. Table 23 presents these various results.

TABLE 23 - No. 3 Pebble Mill Circuit
Specific Power Consumption

SYSTEM	kWh/tonne			% TOTAL COMMIN-UTION
	GRINDING	AUXIL.	TOTAL	
Tornado Crusher	5.14	.30	5.44	95
Pebble Mill	43.9	1.6	45.5	96
Air Sifter (Apex 400)	-	26.0	26.0	-
Air Sifter (Apex 700)	-	36.4	36.4	-

The No. 3 pebble mill power consumption is somewhat higher than that of No. 2 pebble mill as it could be expected for a finer product. The consumption for the sifters is shown in auxiliaries and represents for the Apex products an addition to the energy already expended in the pebble mill.

The range of specific consumptions found for both pebble mills presents a close resemblance with that of clinker grinding, in the cement industry, for a similar size range. It shows that nepheline syenite is a hard mineral to grind and the grindability indices reported in Section 4.14 are appropriate.

4.5 Dust Collection

4.51 Electrical Measurements

Throughout the milling plant, dust control is effected by a bank of thirteen dust collectors that are distributed along the entire process flowline without being attached to specific crushing or grinding circuits. Amperage measurements were made on the fan motors of these various units. Using the nominal power rating and a power factor estimate, power demand estimates have been calculated for each of these motors. The data is presented in Table 24.

TABLE 24 - Milling Plant Dust Collectors

UNIT NO.	MOTOR HP	AMPS	POWER FACTOR	kW
1	40	31	0.70	21
2	45	24	0.60	14
3	30	29	0.75	21
4 (north)	30	18	0.64	11
(south)	25	20	0.71	14
5	40	33	0.72	23
6	15	13	0.73	9
7	25	14	0.62	8
8	50	40	0.71	27
9	50	35	0.68	23
10	40	31	0.70	21
11	15	12	0.71	8
12	40	30	0.69	20
13	40	31	0.70	21
Total	485	-	-	241

The summation makes a sizeable total power demand that must be taken into account to calculate specific power consumptions for various products. The total power demand represents a 67% loading of total installed power.

4.52 Specific Energy Consumption

Because it was not possible to assign individual dust collector units to specific circuits, the power consumption for dust collection is allocated to products on the basis of total plant production rate. The plant daily production is estimated at 980 tonnes, making an average production rate of 40.8 t/h.

By dividing the total power demand of 241 kW by the average production rate, a specific power consumption of 5.90 kWh/tonne is obtained for dust collection. This value will be used for calculating specific consumption by product.

4.6 Products Specific Energy Consumption

4.61 Glass Products

An average specific energy consumption for glass products is established on a cumulative basis including ore crushing, Exolon feed preparation, final sizing and dust collection. The summation of these various specific consumptions is presented in Table 25 as well as their distribution.

The ore crushing specific consumption is adjusted to take into account tailings lost as wasted dust and Dings rejects (overall recovery factor of 72%). The final sizing consumption includes 25% of the Tornado circuit power demand, this being the fraction allocated to glass products.

TABLE 25 - Glass Products Power Consumption
Average Specific Consumption

	kWh/tonne	%
Ore Crushing	3.22	21
Exolon Feed Preparation	5.76	37
Final Sizing	0.60	4
Dust Collection	5.90	38
Total Consumption	15.5	100

The main comments are as follows:

- The Exolon feed preparation accounts for a large fraction of total consumption and the comminution consumption due to the fourth stage of crushing explains 96% of this item.

- The total comminution consumption is only 44%. This is due mainly to dust collection, which accounts for 38%, and ore drying.

4.62 Ceramic Products

The specific energy consumption for ceramic products is established on a cumulative basis including ore crushing, Exolon feed preparation, pebble milling and dust collection. The summation of these various items is presented in Table 26 for the respective pebble mill circuits.

The ore crushing consumption is adjusted according to the process recovery factor (72%). A proportion of 75% of the Tornado crusher power demand is allocated to No. 3 pebble mill.

TABLE 26 - Ceramic Products Power Consumption
Average Specific Consumption

	CREST		PEAK	
	No. 2 Pebble Mill		No. 3 Pebble Mill	
	kWh/tonne	%	kWh/tonne	%
Ore Crushing	3.22	6	3.22	5
Exolon Feed Preparation	5.76	10	5.76	9
Tornado Crusher	-	-	5.32	8
Pebble Milling	39.8	73	45.5	69
Dust Collection	5.90	11	5.90	9
Total Consumption	54.7	100	65.7	100

As expected, milling power consumption is the main item accounting for about 70% of total consumption for both ceramic products. As a consequence, the total comminution consumption, which is about 80%, is also high and even more so, in the case of No. 3 pebble mill, on account of the Tornado crusher consumption. Admittedly, the latter item depends on the arbitrary power demand (75%) allocated to No. 3 pebble mill production. But, on milling alone, No. 3 pebble mill consumption is 14.4% higher than that of No. 2 pebble mill, which is understandable, considering the difference in product fineness. Including the Tornado consumption, it becomes 27.8% higher than for No. 2 pebble mill product: this is felt to be too large a difference between the two milling circuits despite the difference in product fineness.

4.63 Filler Products

The specific energy consumption for Apex 400 and Apex 700 products is presented in Table 27 by simply adding the specific air sifter consumption to the already established No. 3 pebble mill consumption.

TABLE 27 - Filler Products Power Consumption

	APEX 400		APEX 700	
	kWh/tonne	%	kWh/tonne	%
No. 3 Pebble Mill	65.7	72	65.7	64
Air Sifter System	26.0	28	36.4	36
Total Consumption	91.7	100	102.1	100

The data show the importance taken by the air sifter in power consumption, accounting for about one third of the total. Because this consumption is solely for classification, the total for comminution decreases proportionally. But the large consumption impact of the air sifter system may not be fully significant in view of its low electric loading (see 4.41): it may be oversized for the feed rate it is operated at, meaning that a higher feed rate generating a higher production rate would probably improve the specific consumption determined in this survey. It must be added that little information was available because the air sifter system is considered proprietary to IMC.

In nepheline syenite processing, the power consumption can vary from 15 kWh/tonne for glass grade products, to about 60 kWh/tonne for ceramic grade products and over 90 kWh/tonne for filler grade products. Product sizes range from minus 600 µm for glass grade products, to 90-98% minus 45 µm for ceramic grade products and 90% minus 20 µm or 10 µm for filler grade products.

Comminution is not a major factor in the manufacturing cost, particularly in the case of glass products, where it accounts for about 2-3%. For ceramic and filler products, it is more important, ranging from 5 to 10% of manufacturing cost.

The potential for savings concerning comminution proper appears to be small. Primary and secondary crushing entails a power consumption quite typical for these comminution steps. The same applies for tertiary crushing but, at that stage, the drying operation increases the overall specific consumption for crushed and classified ore. In fact, the dryer drive and draft fan combined consumption represents more than 60% of total ore crushing power consumption. This consumption (1.42 kWh/tonne) appears high and may be the result of an oversizing of the rotary dryer system. Also, it is noted that the draft fan runs at maximum power, which raises the question of a possible excess in drying gases. If it is so, thermal energy is wasted. The drying operation warrants further study and may show a potential for both thermal and electric energy savings.

In the area of Exolon feed preparation, the same comment of minimal savings applies, except to note that the rod mill system is the largest consumer among fourth-stage

crushers. This system may present some quality advantage that was not made known during the field work; the imperfect sampling of crusher products could not give any clue in this regard. Therefore, if no quality advantage is obtained from it, the rod mill should be used the least.

The pebble mills performance seems to be good and in line with what should be expected. The use of the Tornado circuit adds significantly to the specific consumption of products made in the No. 3 pebble mill circuit. It would obviously be advantageous to minimize its use.

Because the processing of nepheline syenite is a long sequence of repeated crushing, screening and magnetic separation, dust collection requirements are large and necessitate the use of numerous units with a total installed power of 485 HP (milling plant only). Power demand for dust collection has been estimated at 241 kW and thus represents a major factor in overall power consumption, particularly in the case of glass products. A thorough study would be needed to uncover any potential for savings in that area.

On a product basis, it is seen, for glass products, that power consumption for auxiliaries is larger than for comminution itself (56% versus 44%). The total consumption is typical for the products. The power consumption for ceramic products is also believed to be typical of fine materials. Any savings potential lies in the rod mill and Tornado crusher circuits. As for filler products, the consumption increase caused by the finer classification effected in the air sifter is high and accounts for one third of the product total consumption.

APPENDIX

INDUSTRY REVIEW

GENERAL INFORMATION

The Mineral and its Processing[1,2]

Nepheline syenite is a quartz free feldspathic igneous rock consisting of nepheline, potash and soda feldspar, and accessory mafic minerals such as biotite, hornblende and magnetite. It is characterized by high alumina and alkali content and relatively low silica. Nepheline syenite resembles granite in texture and hardness, but is white in colour and relatively common. There are known occurrences in Russia, Scandinavia, India, Canada, United States and other parts of the world.

Although nepheline syenite is a rock type present in many parts of Canada, its industrial application is limited to those deposits from which iron-bearing accessory minerals can readily be removed. Its major uses are in the glass and ceramic industries.

The use of nepheline syenite as a raw material for glass, ceramic and the filler industries was first developed in Canada, the world's sole producer for many years. Canada's only competitor in the field, Norway, began nepheline syenite mining and milling in 1961. Other countries, the USSR and the United States, mine the mineral for other uses, specifically as a source of aluminum in the USSR and for railway ballast and roofing granules in the USA.

Over the years, nepheline syenite has become preferred to feldspar as a source of essential alumina and alkalis for glass manufacture. Its use results in more rapid melting of the bath at lower temperatures than with feldspar, thus reducing fuel consumption, lengthening the life of furnace refractories and

improving the yield and quality of glass. Other industrial uses include ceramic glazes, enamels, and fillers in paints, papers, plastics and foam rubber.

The glass industry accounts for about 70% of nepheline syenite consumption. Use of finely ground material in the ceramics industry and as a filler has grown more rapidly in recent years than consumption for glassmaking. Today, Canada remains the world's foremost producer of nepheline syenite as an industrial raw material with a total capacity amounting to over 800,000 tonnes per year compared to Norway's 225,000 tonnes a year. Typically, Canada exports up to 75% of its production with about 85% of exports going to the United States.

Nepheline syenite ore is mined by the open pit method in Canada while underground mining is used in Norway. The iron content in the Canadian ore body is distributed quite uniformly, but selective quarrying, blending of quarry material, and careful pit development are necessary to ensure a mill product capable of meeting consumer specifications.

Processing of nepheline syenite starts with the diamond drill core evaluations. Analyses of the drill cuttings are made prior to blasting large blocks of material. Ore is graded accordingly.

In the milling plant, the blended ore is reduced in jaw and cone crushers before being dried. The dried ore is further reduced in a tertiary crushing circuit using impact or cone crushers. The crushed ore is then screened to remove the minus 600 μm material and the oversize is further reduced to minus 600 μm using various crushers such as rolls, gyradisc or rod mill.

Magnetite and iron-bearing minerals are then removed using first, low intensity magnetic separators and secondly, high intensity magnetic separators. Two product grades are thus obtained depending on the ore selected in the quarry, one with a Fe_2O_3 content of less than 0.08% and the other with a Fe_2O_3 content of less than 0.3%. These two product grades are sized by series of vibrating screens to produce minus 600, 425 and 300 µm products for the glass industry.

Fine products of the highest grade used in the ceramic, paint and plastics industries are ground in pebble mills operating in closed circuit with air classifiers. The air-classified products range from minus 75 µm to minus 10 µm.

Canadian Industry

Initial interest in the commercial possibilities of the mineral began in 1912 when various deposits were sampled and examined by a company interested in a process for extracting alumina from silicate minerals.[3]

But Canada's nepheline syenite industry really began in 1932 with the staking of fine claims on Blue Mountain in Methuen Township, 40 km northeast of Peterborough, Ontario. Today, there are two mills in operation on Blue Mountain processing rock from several quarries. The deposit is pearshaped, approximately 8 kilometres long, and between 1.6 and 2.5 kilometres wide.[1]

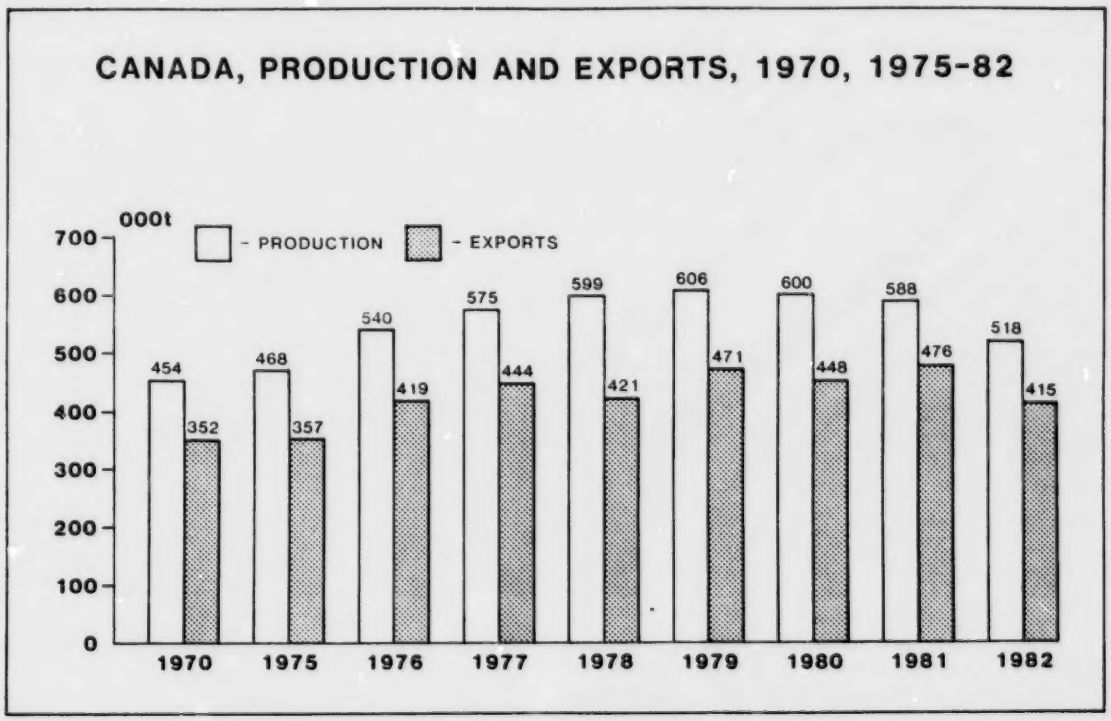
Indusmin Limited, a subsidiary of Falconbridge Nickel Mines Limited, is the larger producer, its annual capacity having been raised to 420,000 tonnes in 1979. It has a large range of products based on combinations of different particle sizes and iron content. The operation is located at Nephton, Ontario,

and exploits the southwest end of the deposit.

IMC Industry Group (Canada) Limited, a wholly owned subsidiary of International Minerals & Chemicals Corporation (IMC) works the northeast end of the deposit. IMC completed an expansion in 1981 that increased capacity by 25% to well over 300,000 tonnes annually. The range of products was also enlarged and some higher value grades are now available.

The production volumes, expressed as producers' shipments, and exports during recent years are shown in the diagram below.

FIGURE 1 - Canada, Production and Exports, 1970, 1975-82[4]
(in thousand tonnes)



Source: Canadian Minerals Yearbook 1982, EMR Canada.

From 1977 through 1981, shipments of Canadian nepheline syenite have been stable at about 600,000 tonnes per year. But, starting in 1981, the industry has been affected by the recession; a 15% fall in shipments occurred in 1982.

Table 1 gives production, exports and domestic consumption breakdowns for 1981 and 1982.

TABLE 1 - Canada, Nepheline Syenite Production, Exports, and Consumption, 1981 and 1982[4]

	1981		1982	
	tonnes	$000	tonnes	$000
Production (shipments)	588 000	16,700,000	518 000	17,338,000
Exports				
United States	399 071	13,423,000	373 930	13,557,000
Italy	12 203	435,000	6 834	495,000
Australia	11 295	408,000	1 537	121,000
Netherlands	8 654	358,000	24 490	1,014,000
United Kingdom	3 740	175,000	4 751	256,000
France	1 149	121,000	821	93,000
Taiwan	311	72,000	526	193,000
Other countries	39 858	266,000	1 896	193,000
Total	476 281	15,258,000	414 785	15,765,000
Consumption[1]				
Glass and Glass Fibre	66 591			
Ceramic Products	16 217			
Insulation	11 368			
Paints	2 039			
Rubber Products	689			
Others[2]	830			
Total	97 734	..	..	..

Sources: Statistics Canada; Energy, Mines and Resources, Canada
1 Available data, as reported by consumers.
2 Includes frits and enamel, foundry, plastics, electrical apparatus and other minor uses.
P Preliminary: .. Not available.

Market Outlook

The rapid growth of nepheline syenite consumption in the 60's and early 70's was largely due to the recognition by glass-makers of its superior qualities in terms of chemical consistency, supply reliability and low cost compared to its chief competitor, feldspar. In recent years, competition for Canadian nepheline syenite has continued to come from feldspar and aplite produced in the United States. The substitutability of these inputs for glass and ceramics and the high cost of transport relative to unit value have created stable market areas. The borders of these markets are as much dependent on freight rates as on prices.[4]

The outlook for nepheline syenite continues to be good, although the 1982 recession in the world economy interrupted growth. It is expected that the glass and ceramic industries will continue to be the principal users of nepheline syenite. The wide range of products, now offered by both IMC and Indusmin, and the established high quality of products should allow an increase of sales in the medium term. However, any large scale increase in shipments will depend on the performance of the glass and ceramics industry, which in turn is dependent on the North American economy in general.[4]

Exports offshore should continue to grow with expansion of European markets, since the only western European nepheline syenite producer, Norsk Nefelin, division of Elkem A/S, is already operating at capacity.

PRODUCT CHARACTERISTICS[5]

Industrially, there are no standard specifications for nepheline syenite. However, nepheline syenite used for glass-making is typically a product with a size distribution between 600 and 75 μm, an alumina content in excess of 23%, an alkali content in excess of 14% and an iron oxide content of less than 0.08%.

For the ceramic industry, a fineness of less than 75 μm is required as well as its qualities of high fluxing and low level of iron and other impurities.

In the extender pigment and filler industries, the important qualities are the following: high dry brightness, chemical uniformity and inertness, high bulking value and high specific index of refraction.

In general, market requirements vary and, for instance, North American markets require 0.08% Fe_2O_3 or less while European markets accept 0.1% Fe_2O_3 content. Norwegian nepheline syenite products are higher in alumina and alkalis than Canadian ones. Other contaminating metallic ions must be at acceptably low levels and refractory minerals must be absent.

Typical chemical and physical characteristics are presented in the following tables.

TABLE 2 - Chemical Analysis of a Nepheline Syenite Product[6]

Component	%
SiO_2	60.1
Al_2O_3	23.3
Fe_2O_3	0.07
CaO	0.7
MgO	0.1
Na_2O	10.1
K_2O	4.9
LOI	0.65

TABLE 3 - Properties of Nepheline Syenite[6]

Specific Gravity	:	2.61
Hardness (Mohs scale)	:	5 - 6
Refractive Index	:	1.53
pH	:	9.6
Pyrometric Cone	:	6 - 7

Although, taken as a whole, the deposits are remarkably uniform in chemical and mineralogical comsumption, it has been found that in certain areas, the rock is less amenable to treatment. Consequently, control of the chemical composition of the final product must and does commence before actual mining operations begin. In the laboratory, core samples from the undeveloped quarry zones are subjected to a treatment duplicating, on a small scale, the actual mill flow sheet and complete chemical analyses are made of each product. This method ensures uniform chemical composition of future production.

During quarry exploitation, chip samples are taken and analyzed for chemical uniformity and iron content. Any irregularities require blending of rock from several faces.

Quality control in the mill is concerned primarily with particle size distribution. Regular checks are made of the screen products. Sieve analysis and sub-sieve analysis are carried out for both the glass grade and ceramic grade products. It has been established that, where mill conditions are constant, there is a correlation between sieve and sub-sieve analyses.

Iron assays are made on mill samples to provide a measure of performance of the magnetic separation stage in the mill.

Each shipment made is drawn from the storage bins in an established pattern to guard against variation due to segregation. Also, complete sieve and iron content analyses of representative samples are reported and maintained for each shipment. Complete chemical analysis and checks for fired colour, fusibility and biotite specking are made monthly.

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THE POTASH INDUSTRY

ENERGY CONSERVATION IN THE INDUSTRIAL
MINERALS PROCESSING SECTOR - COMMINUTION

(Phase I - Plant Studies)

Work on this Project was conducted by
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1. INTRODUCTION

Cooperating Company:

P.C.S. Mining Ltd.
Cory Division

Plant Location:

Saskatoon, Saskatchewan

The report introduces first the company that cooperated in the study. A description follows of the comminution processes monitored during the field work at the company's plant. The measurements made and results obtained are then reported and discussed and conclusions drawn.

For readers who are not familiar with the potash industry, an appendix entitled "Industry Review" is added. Details concerning data collection and field work, as well as other raw data or measurements, are available in working papers.

2.1 Potash Process Flow

The flowline at the PCS Cory Division mill involves a range of process principles (Fig. I). The processes include impact crushing and screening, desliming, flotation, centrifuging and product crystallization. It is a wet process from the secondary screening stage to flotation and crystallization. Product screening and handling follow the drying operations.

The Cory process is arranged into four major steps:

- ore processing and flotation feed preparation,
- flotation with tails and slimes handling,
- two crystallization circuits for manufacture of white products,
- pink product screening and compaction.

The last step includes final drying and screening for both the soluble and refined white products.

Due to the seasonal nature of the market, the Cory plant requires extensive product handling and storage facilities so that product stocks can be built up to meet the requirements of peak demand.

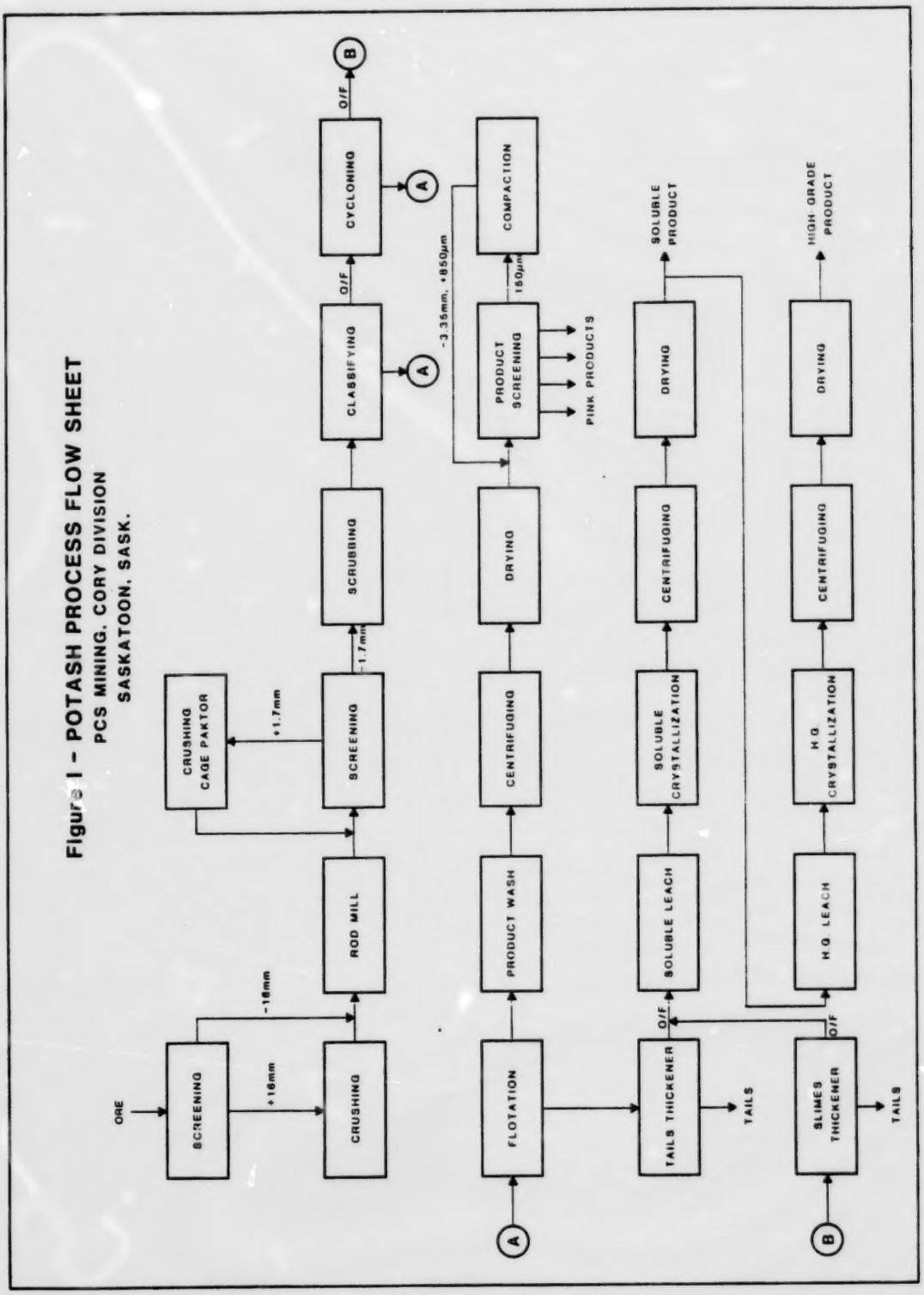


Figure 1 - POTASH PROCESS FLOW SHEET
PCS MINING, CORY DIVISION
SASKATOON, SASK.

2.2 Ore Processing

It is important in potash processing to maintain as large a particle size as possible[4] while still liberating the KCl since fertilizer application requires a relatively coarse product. Also, liberation of sylvite must be sufficient to meet the 95% KCl minimum requirement.

Processing at PCS Cory begins with the mine-run ore passing over a primary scalping screen (Fig. II) with +16 mm material being fed to a 200 HP impact crusher. Approximately 12-15% of the ore is large enough to require primary crushing. The primary screening and crushing operations are dry. The crusher product and primary screen undersize are mixed and, at this point, brine is introduced and the mixture fed to a 500 HP variable speed rod mill. From this stage until final product drying, the Cory mill is wet process.

The rod mill product passes to the primary scrubber which begins the process of removing the clay particles from the crystal surfaces. The removed clay goes into suspension in the brine. This mixture then passes to four secondary wet-screens operating in parallel. The +2 mm oversize is fed to a two concentric squirrel cagepaktor powered by 125 and 150 HP motors on the inner and outer cages, respectively. The cagepaktor product returns to the outlet of the rod mill and thence to the primary classifier in a closed-circuit loop. The option exists for the cage mill to be bypassed with wet-screen which removes the oversize to the rod mill. This is not normally done since overall throughput is severely hampered with the cage mill shutdown. Comminution and associated equipment in the primary circuit are listed in Table 1.

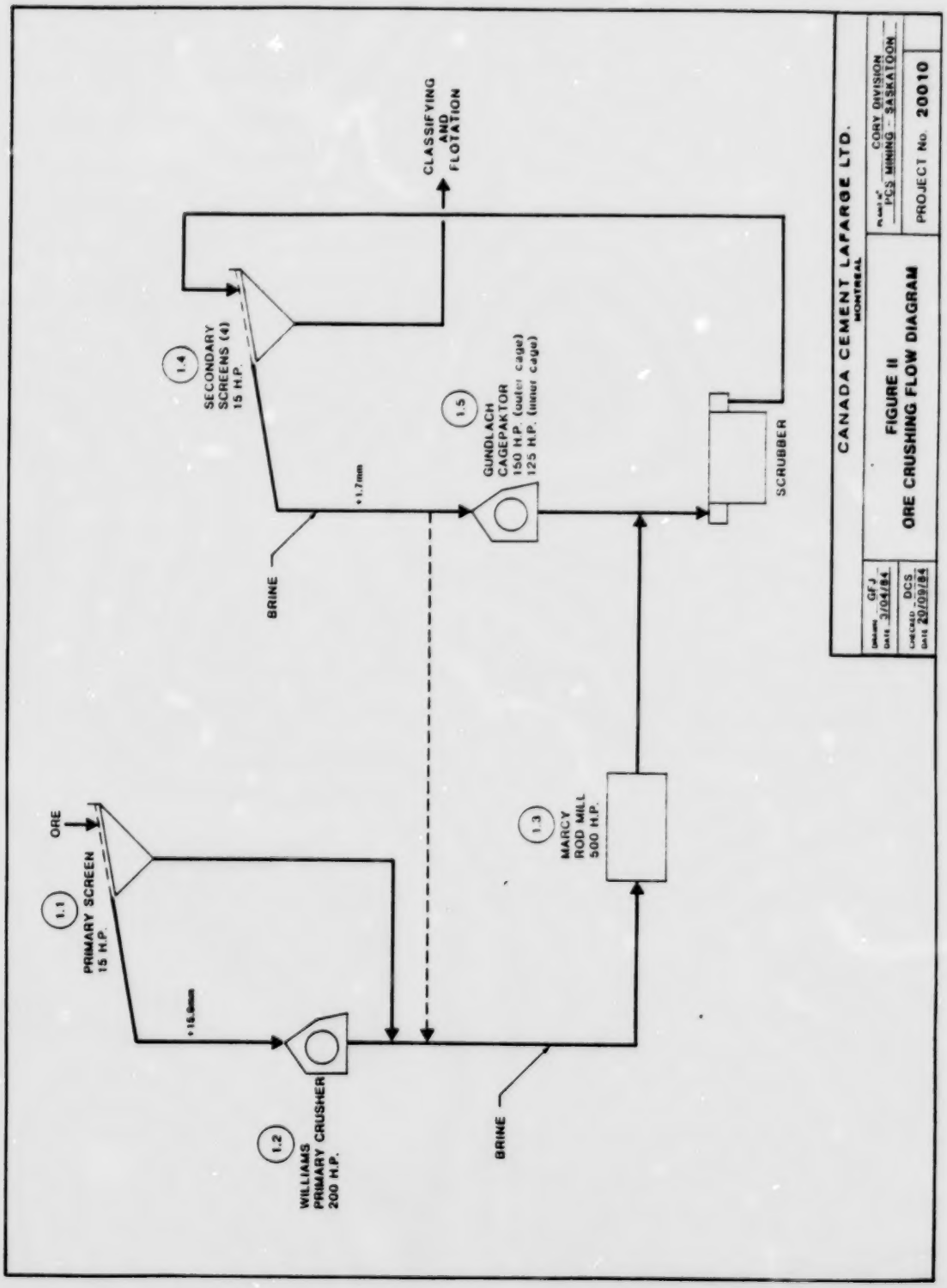

ORE
1.1
PRIMARY SCREEN
15 H.P.
+16.0mm
1.2
WILLIAMS
PRIMARY CRUSHER
200 H.P.
1.3
MARCY
ROD MILL
500 H.P.
BRINE
BRINE
1.4
SECONDARY
SCREENS (4)
15 H.P.
+1.7mm
1.5
GUNDLACH
CAGEPAKTOR
150 H.P. (outer cage)
125 H.P. (inner cage)
SCRUBBER
CLASSIFYING
AND
FLOTATION
CANADA CEMENT LAFARGE LTD.
MONTREAL
DRAWN GFJ
DATE 3/04/84
CHECKED DCS
DATE 20/09/84
FIGURE II
ORE CRUSHING FLOW DIAGRAM
PROJECT CORY DIVISION
PCS MINING - SASKATOON
PROJECT No. 20010

TABLE 1 - Ore Processing Equipment List

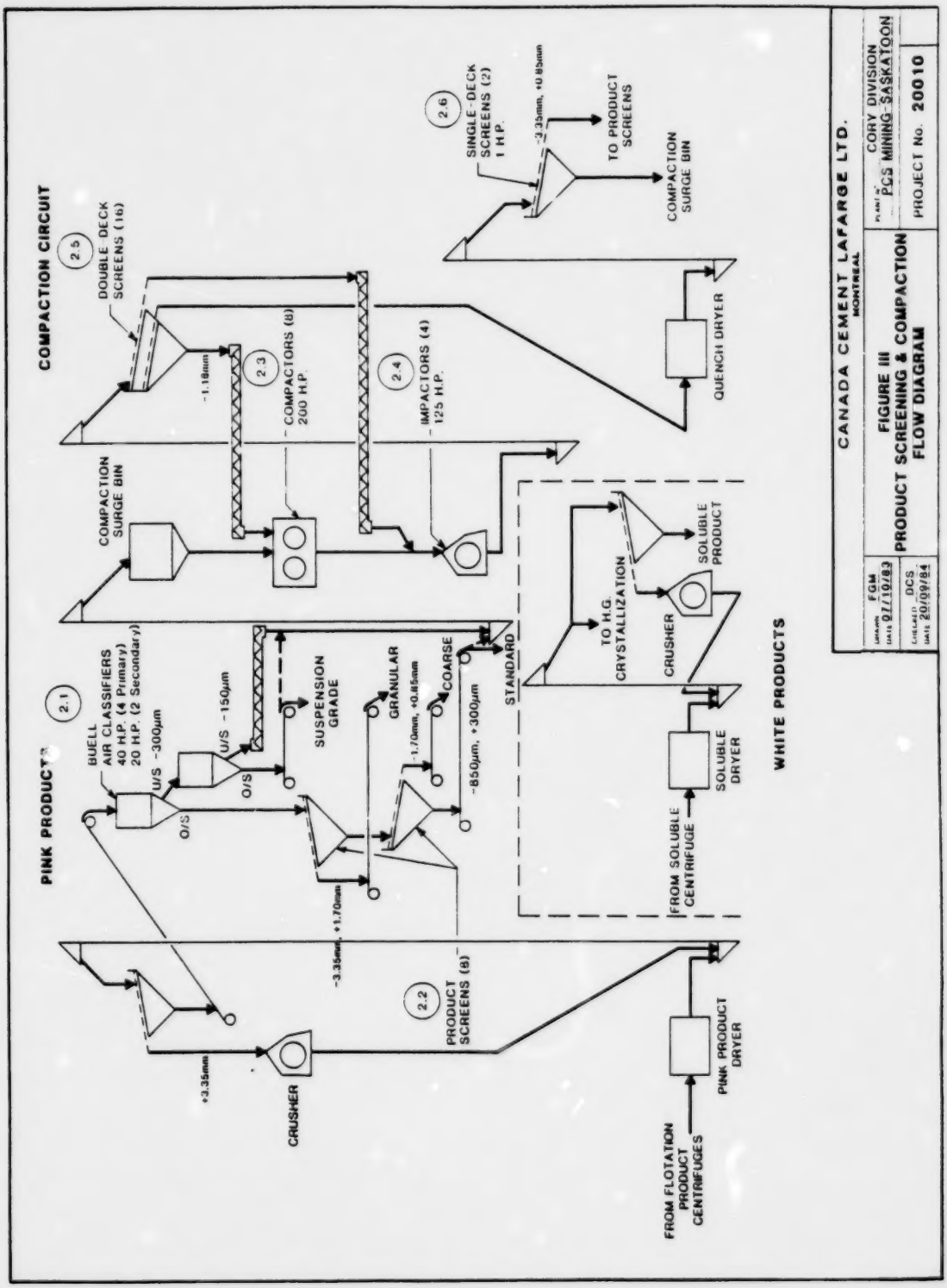
No.	EQUIPMENT TYPE/MAKE/MODEL	MOTOR	
		H.P.	AMPS
1.1	Primary Screen	15	15
1.2	Primary Crusher - Williams Type K Size #340 Reversible	200	200
1.3	Rod Mill - Marcy 440 V DC 10'10" dia. x 14' Open End	500	1130
1.4	Secondary Screens (4)	15	15
1.5	Cagepaktor - Gundlach 50-2C4R-B		
	Outer Cage	150	150
	Inner Cage	125	125

Note: All motors 550 volt except where noted.

The wet-screen undersize, being the product of the comminution circuit, now passes through various stages of scrubbing, classifying and hydrocycloning to prepare a feedstock for the flotation circuit. The description and operation of these circuits is omitted since they are not directly involved in size reduction.

2.3 Product Screening and Compaction

The product drying, screening and compaction circuits (Fig. III) are involved in processing the "pink" or floated products. The pink cake from the flotation product centrifuges is dried in rotary dryers and passed over a scalping screen with the +3.35 mm oversize being fed to a 25 HP "lumpbreaker" crusher and returned to the screen. The undersize is fed to four primary air classifiers operating in parallel. Air classifying involves passing the feed material down through a cross-flow stream of air with heavier particles passing through the stream


COMPACTION CIRCUIT
PINK PRODUCTS
WHITE PRODUCTS
2.1
BUELL AIR CLASSIFIERS 40 H.P. (4 Pumary) 20 H.P. (2 Secondary)
U/S -300µm
U/S -150µm
O/S
O/S
SUSPENSION GRADE
GRANULAR
COARSE
STANDARD
-1.70mm, +0.85mm
-850µm, +300µm
-3.35mm, +1.70mm
+3.35mm
CRUSHER
2.2
PRODUCT SCREENS (8)
FROM FLOTATION PRODUCT CENTRIFUGES
PINK PRODUCT DRYER
FROM SOLUBLE CENTRIFUGE
SOLUBLE DRYER
TO H.G CRYSTALLIZATION
CRUSHER
SOLUBLE PRODUCT
COMPACTION SURGE BIN
2.5
DOUBLE DECK SCREENS (16)
-1.18mm
2.3
COMPACTORS (8) 200 H.P.
2.4
IMPACTORS (4) 125 H.P.
COMPACTION SURGE BIN
QUENCH DRYER
2.6
SINGLE-DECK SCREENS (2) 1 H.P.
-3.35mm, +0.85mm
TO PRODUCT SCREENS
COMPACTION SURGE BIN
CANADA CEMENT LAFARGE LTD.
MONTREAL
DRAWN FGM DATE 07/10/83
CHECKED DCS DATE 20/09/84
FIGURE III
PRODUCT SCREENING & COMPACTION FLOW DIAGRAM
PLANT PCS MINING-SASKATOON
CORY DIVISION
PROJECT No. 20010

to coarse product and the lighter particles being entrained in the air stream and being subsequently cycloned out as fine product. The "cut-point" is adjusted by changing the air flow. The +300 μm coarse product from the primary air classifiers is fed to four product screens in parallel. The +2.00 mm oversize serves as -3.35 +2.00 mm granular product. The undersize passes to a second set of four product screens in parallel where the +850 μm oversize becomes -2.00 mm +850 μm coarse product. The undersize is -850 +300 μm standard product.

The fine product from the primary air classifier is fed to two secondary air classifiers in parallel. The +150 μm coarse fraction from these classifiers serves as -300 +150 μm suspension product. The fine product from the classifiers is sent to the compaction circuit. The finer standard and suspension products, depending on demand, can also be sent to compaction for size enlargement to make coarser product.

Cory has two compaction circuits, each consisting of four 200 HP compactors in parallel and two 125 HP impact crushers in parallel. Each circuit also has a set of eight vibrating screens in parallel and a rotary quench dryer.

The compaction circuit feed is held in a surge bin and distributed to the roll-type compactors where it is compressed to a high density flake through the application of high pressures on the rolls. This material then passes through the impactors and is fed to the vibrating screens where a -3.35 +1.40 mm mid-fraction is removed. The oversize and undersize return to the impactors and compactors,

respectively. The mid-fraction is dried in a rotary quench dryer and fed to two vibrating screens in parallel with the +850 μm oversize going to the product screens and the undersize being returned to the compaction surge bin. Product screening and compaction equipment is listed in Table 2.

TABLE 2 - Product Screening and Compaction

No.	EQUIPMENT TYPE/MAKE/MODEL	MOTOR	
		H.P.	AMPS
2.1	Buell Air Classifiers		
	Primary (4)	40	40
	Secondary (2)	20	20
2.2	Product Screens (8) 230 V	-	-
2.3	Compactors (8)	200	200
2.4	Compaction Crushers (4) Pennsylvania Type CAL7-38	125	125
2.5	Compaction Double-Deck Screens (16) 230 V	-	-
2.6	Compaction Single-Deck Screens (2) 110 V	3 x 1/3	2

Note: All motors 550 volt except where noted.

With regard to the processing of white products, the cake from the soluble centrifuge is dried in a rotary dryer and passed over a screen with the oversize being fed to a 30 HP "lumpbreaker" crusher and returned to the screen. The undersize goes to product handling and storage as soluble product. The cake from the H.G. centrifuge is dried in a rotary dryer and becomes finished high-grade product.

3.1 Ore Processing

3.11 Electrical Measurements

Electrical data obtained during the field work pertaining to ore processing is presented in Table 3. The reported kilowatt data was calculated from observed volt, amp and power factor readings.

TABLE 3 - Ore Processing

(Measurements)

No.	EQUIPMENT	MOTOR HP	POWER OBSERVATIONS - kW		
			MAX.	MIN.	AVG.
1.1	Primary Screen	15	5	5	5
1.2	Primary Crusher	200	160	105	127
1.3	Rod Mill	500	435	326	370
1.4	Secondary Screens (4)	15	4	4	4
1.5	Cagepaktor				
	Outer Cage	150	81	65	73
	Inner Cage	125	53	40	47

The measurements indicate that the primary screen was operating well within its power limit although it produces the entire volume of mill feed. The primary crusher measurements reveal, on average, that the crusher operates within its power capacity although the maximum power draw does approach the limit. However, the measured power factor was very good (near 1) and, with the crusher handling 12-15% of the mill feed presently as compared to 35% in the past, the crusher is not overloaded.

The rod mill electrical measurements indicate that the drive is reasonably loaded on average. The maximum power draw does not present an overload problem since the power factor is high. The kilowatts were calculated treating the drive as direct current, single-phase. The D.C. drive is necessary since some rod mill speed adjustments may be necessary from time to time. The secondary wet-screens are operating well within their power capacity.

Both cagepaktor motors appear to be operating under the same degree of loading according to the measurements. The loading is moderate with even the maximum power draw well below the limit. However, the cagepaktor loading depends entirely on the amount of circulating load in the ciruit. When measured, the power drawn by the cagepaktor was well below installed capacity.

3.12 Flowrates

Stream flowrates for the ore processing circuit were obtained from a material balance carried out previously by the plant staff at Cory and based on a mill ore feed rate of 450 t/h. This exercise had been done to determine the effect of the cagepaktor on the circuit and especially on the rod mill. Prior to the installation of the cagepaktor, the rod mill had operated in closed circuit with the secondary wet-screens and had performed all comminution work in the ore processing circuit after the primary crusher. After the installation, the cagepaktor operates in closed circuit with the wet-screens with cagepaktor and rod mill discharge being fed to the screens. The rod mill now operates in open circuit. However, the cagepaktor can be bypassed for repairs and the rod mill returned to closed circuit.

The primary screen separates out the +16 mm particles in the ore as feed for the primary crusher. The flowrate through the primary crusher was estimated from a typical screen analysis of the ore provided by Cory plant staff and selecting the split at 16 mm determined by linear interpolation. The crusher flowrate was calculated by taking the +16 mm fraction as a percentage of 450 t/h.

Secondary screen and cagepaktor feedrates were used as reported in plant records. The flowrate data is summarized in Table 4.

TABLE 4 - Ore Processing Flowrates

	t/h
Primary Screen	450
Primary Crusher	63.5
Rod Mill	450
Cagepaktor Discharge	260
Wetscreens Undersize	450

3.13 Size Distribution

Size distributions of various streams in the ore processing circuit (Table 5), as with flowrates, were obtained from the Cory Metallurgical Lab reports.

Primary crusher feed was estimated from the reported ore size distribution based on a split at 16 mm.

TABLE 5 - Ore Crushing Circuit - Size Distributions

SIEVE Opening	ORE % Passing	PRIMARY CRUSHER		ROD MILL		CAGEPAKTOR	
		Feed	Disch	Feed	Disch	Feed	Disch
32.0 mm	100	100					
26.7	92.0	43.0					
18.9	88.0	14.0	100	100			
13.3	83.1		82.3	98.3		100	
9.42	77.2		74.6	94.1	100	98.7	100
6.00	70.8		67.0	86.1	99.0	93.7	99.4
4.75	64.0		60.9	79.3	97.5	82.8	98.5
3.35	56.9		53.3	71.7	94.5	58.9	91.7
2.36	48.9		45.1	63.3	87.1	19.2	78.6
2.00	41.1		37.2	54.7	81.4	5.8	55.2
1.40	34.1		29.8	46.7	70.3	2.8	39.9
850 μm	28.7		23.8	40.5	60.7	1.8	30.1
600	22.8		18.0	33.7	49.1	1.2	20.6
500	18.1		13.4	28.3	39.9	0.9	15.2
300	13.8		9.5	23.4	31.1	0.7	10.8
250	10.3		6.6	19.4	23.4	0.7	8.2
150	7.2		4.5	15.7	13.7	0.7	6.3
106	4.8		3.1	11.8	11.3	0.7	4.5

Rod mill feed, being a combination of primary screen undersize and primary crusher discharge, is shown to be finer than primary crusher discharge. This implies the relatively high fineness of primary screen undersize

compared to primary crusher discharge and confirms the presence of the significant amount of fines in the ore from the mine.

Comparison of rod mill and cagepaktor feeds reveals that most of the fines have been removed by the secondary screens. Cagepaktor discharge fineness is comparable to rod mill discharge fineness in the larger sizes but drops off more rapidly in the smaller sizes. This is at least partly due to the fact that cagepaktor feed has passed over the secondary screens, whereas the rod mill receives fines which are already present in the ore.

3.14 Grindability

The results of grindability testing of a sample of rod mill feed are summarized as follows:

Bond Work Index	: 13.55 kWh/Ton
Hardgrove Grindability Index	: 55
Bond Work Index Calculated	: 11.34 kWh/Ton

These results indicate a material that is difficult to grind. However, lab grindability results may be overstated because, under the test conditions, the material is ground significantly finer than actually occurs in the process. For example, in the plant process, the material is ground to less than 10% passing 100 µm, while the grindability test reduces the material to 75 µm.

The nature of potash ore is such that the sylvite and halite crystals are separated at a certain size depending on the ore. The objective of comminution is to grind sufficiently fine to produce individual crystals and meet the 2.00 mm minimum fineness for flotation. At this size

requirement, much of the comminution work goes towards separating the individual crystals within the mass. The forces holding the crystals together are small since crystal surfaces are well defined and particles of clay are located between crystals. However, at minus 75 μm, more energy is being spent to break up individual crystals where the binding forces are greater. Therefore, the Bond Grindability test, as conducted, may not relate well to what is actually happening in the process, indicating a much harder material than seems to be observed in practice.

3.15 Energy Consumption

Power Consumption data pertaining to the ore processing circuit (Table 6) shows that the consumption of electrical energy is quite small overall. The three comminution devices, impactor, rod mill and cagepaktor, use 97% of the circuit's energy demand. The two screening steps account for the remainder.

TABLE 6 - Potash Ore Comminution
Specific Power Consumption

Flowrate: 450 t/h

	kWh/tonne	%
Comminution	1.36	97
Auxiliaries	0.04	3
TOTAL	1.40	100

Comminution energy in the ore processing circuit is low for two reasons. The ore is easy to grind and the degree to which the ore must be ground is moderate.

3.2 Product Screening and Compaction

3.21 Electrical Measurements

Electrical results (Table 7) for the final pink product classifying phase of the process show that, for this stage, the main electrical power draw is by the eight compaction units. Although there is over 200 HP installed in the Buell air classifier units, the measurements show that the motors are operating at about half load, thereby reducing the overall power draw. The energy consumption of the classifiers, in the form of circulating air fans, is quite steady with little fluctuation in kilowatts.

The compaction units, each rated at 200 HP, were shown to be well loaded with good power factor. Despite the large power draw of the compactors, there is little fluctuation, due to the steady feed rate of each unit.

TABLE 7 - Product Screening and Compaction

(Measurements)

No.	EQUIPMENT	MOTOR HP	POWER OBSERVATIONS - kW		
			MAX.	MIN.	AVG.
2.1	Buell Air Classifiers				
	Primary (4)	40	15	15	15
	Secondary (2)	20	6	6	6
2.2	Product Screens (8)	-	3	3	3
2.3	Compactors (8)	200	140	140	140
2.4	Compaction Crusher (4)	125	40	28	33
2.5	Compaction Double-Deck Screens (16)	-	3	3	3
2.6	Compaction Single-Deck Screens (2)	3 x 1/3	1	1	1

Four compaction crushers or impactors immediately follow the compactors in the process flow. The loading of the impactor motors is quite low, averaging about a third of capacity and a maximum power draw less than half capacity. The measurements also indicate some fluctuation in kilowatts drawn by the impactors is caused by the introduction of larger pieces of feed.

3.22 Flowrates

The pink product flowrate is calculated from the mill ore feed rate based on a 3:1 ore to pink product yield ratio. This production rate is taken as the throughput of the Buell air classifiers.

Flowrates in the compaction circuit are based on a circuit throughput rate of 7-8 t/h per compactor as indicated during the field work. Since this throughput rate agrees closely with design estimates, remaining compaction circuit flowrates are taken from design figures, allowing for minor corrections to close the mass balance. A circulating load of approximately 300% exists in the compaction circuit. It is split into two parts: an undersize return stream to the compactors and an oversize return stream to the impactors. The individual flowrates for the oversize and undersize fractions of the circulating load are nearly the same. The compaction circuit throughput rate is based on the indicated throughput rate per compaction unit with all compactors operating.

The compaction circuit product is fed to the product screens and can end up in any of the products. Most of the pink product demand is for the granular and coarse products. The flowrate data is summarized in Table 8.

TABLE 8 - Product Screening & Compaction Flowrates

	t/h
Air Classifier Feed	150
Compactor Output	19.4
Impactor Output	58.8
Compaction Circuit Output	58.1
Pink Products	150

3.23 Size Distribution

Particle size information of various process streams in the product screening and compaction department is expressed as range of size of particles for the stream in question.

The feed to the compaction circuit is -150 μm from the second stage Buell air classifiers, although larger if standard or suspension material is directed to compaction. An important feature of the compaction circuit is that, of the material processed through the impactors, only the -3.35 +1.40 mm mid-fraction is selected for drying. The oversize returns for size reduction and the undersize returns for size enlargement at the compactors. Any -850 μm material generated in the mid-fraction by drying and handling is screened out and again returned to the compactors. As mentioned earlier, the material must be in a specific size range before becoming final product.

3.24 Energy Consumption

Specific power consumption for compaction and screening of pink products (Table 9) includes electrical energy consumed by air classifiers and product screens as well as screens in the compaction circuit. The results for the compaction circuit are included for comparative purposes but are not regarded as comminution.

TABLE 9 - Compaction and Screening Specific Power Consumption

Flowrate: 150 t/h

	kWh/tonne	%
Comminution	0.88	46
Auxiliaries	1.05	54
TOTAL	1.93	100

The proportion of total specific energy represented by comminution energy in this stage of processing is relatively low. Comminution energy represents less than half the total since the four compaction crushers are not heavily loaded and operate in conjunction with the air classifiers and numerous sets of screens.

Total and comminution energy consumption for pink products is given in Table 10. The reported energy is cumulative, representing consumption over all stages of the process where comminution and classifying occur.

TABLE 10 - Pink Products
Cumulative Power Consumption

Flowrate: 150 t/h

	kWh/tonne	%
Comminution	4.96	81
Auxiliaries	1.17	19
TOTAL	6.13	100

Pink Products
Compaction Power Consumption
7.47 kWh/tonne

Cumulative energy is calculated allowing for the 3:1 yield ratio at flotation. The total energy is low, at just over 6 kWh/tonne. Comminution energy represents a much greater portion of the total than at compaction and screening alone since comminution accounted for a very high proportion of energy consumed in primary ore processing. Nonetheless, the percentage of cumulative auxiliary energy is significant, representing several screening and classifying steps.

Finally, electrical consumption by compaction is calculated and reported, distributed over pink products. This energy is significant, being greater than cumulative comminution and auxiliary energy and 50% greater than cumulative comminution energy alone.

Overall, the comminution and associated energy required to process potash ore into pink products at Cory is relatively low. Comminution occurs chiefly for manufacturing pink products with little comminution energy required for white products. Compaction is a considerable consumer of energy in pink product manufacture, actually being greater than comminution and auxiliaries combined. The energy consumption reported is averaged over all pink products, despite the fact that the production rate for individual pink products varies according to demand.

The primary ore crushing circuit appears to be making efficient use of energy for comminution with a high throughput of 450 t/h. The combined energy required for comminution and screening is 1.4 kWh/tonne, although this low value is offset somewhat by the fact that roughly three tonnes of ore must be processed through the primary circuit for each tonne of finished material produced.

Particle size distribution data indicate that much of the very fine particles is present in the ore received at the mill because considerable size reduction takes place during mining. The cagepaktor appears to produce fewer fines than the rod mill. Fines generation at the rod mill depend on the mill loading and whether it is operated in open or closed circuit. It is desirable to prevent very fine particles from being produced since they have a tendency to be entrained to slimes handling. Any improvements to the primary circuit from the present arrangement would be towards improving throughput and would be expected to have only a small effect on energy consumption.

The final pink product comminution energy consumption was calculated to be about 6.1 kWh/t with another 7.5 kWh/t required for compaction. The compactors represent the greatest energy consumption with 8 units, each rated at 200 HP. The compaction step represents a high energy consumption due to the nature of the operation with the rollers acting under high pressures. Also, the throughput of each compactor is relatively small for the power required.

APPENDIX

INDUSTRY REVIEW

GENERAL INFORMATION

General

Potash is the generic term used for a range of potassium bearing minerals, ores and refined products. Potassium, along with nitrogen and phosphate is one of the three essential plant nutrients. Potash is used mainly as a fertilizer and the major markets are in the developed countries.

The principal product is potassium chloride (KCl), commonly called "muriate". It accounts for 80% of the world potash production and is the sole Canadian potash product. The other salts which are marketed are potassium sulfate (K_2SO_4: U.S.A., U.S.S.R., Europe) and potassium magnesium sulfate (K_2SO_4, $2MgSO_4$: U.S.A., West Germany).

The U.S.S.R. is the largest producer and accounted for about 35% of the estimated world production in 1982. Canada follows with 21% of the world production. Potash production volumes since 1977 of the three major producers are shown in Table 1.

TABLE 1 - U.S.S.R., Canada, U.S.A. and World Potash Production 77-82[5,8]

	(thousands of tonnes K_2O equivalent)					
	1977	1978	1979	1980[P]	1981[e]	1982[e]
U.S.S.R.	8 347	8 193	6 635	8 064	8 350	8 600
Canada	5 764	6 340	7 074	7 532	6 815	5 208
U.S.A.	2 229	2 253	2 235	2 239	2 156	1 782
Total World	25 252	26 113	25 677	27 673	27 357	24 729

[P] Preliminary
[e] Estimate

The major identified world potash resources are listed in Table 2. They represent several hundred years of consumption at current rates of exploitation.

TABLE 2 - Identified World Potash Resources[7]

	Million tonnes of K_2O
Canada	74 000
U.S.S.R.	55 000
U.S.A.	6 000
World	151 000

These salts are mined from marine chloride evaporate deposits (85% of the world production in 1975) from natural brines. The three predominant minerals which occur in Western Canadian potash bearing zones are shown in Table 3.

TABLE 3 - Western Canadian Potash Ore Composition

Mineral	Chemical Composition	Concentration in Ore (%)
Halite	(NaCl)	40 - 60
Sylvite	(KCl)	35 - 50
Carnallite	($KCl.MgCl_2.6H_2O$)	0 - 6
Insolubles	---	2 - 8

The insolubles include clay minerals, anhydrite, dolomite and calcite.

The ore is a "mechanical" mixture, in that the sylvite and halite are present as individual crystals and can be separated by breaking the total mass down to a maximum size of 3 to 12 mm, depending on the ore. The clay adheres to the surface of the crystals and is removed by washing or "scrubbing".

Sylvite has a vitreous luster, is very plastic under pressure and ranges in colour from clear to brick red. The colouration is due to impurities.

The Saskatchewan potash ore is located between 900 and 1000 meters beneath the surface in a seam which is flat and is 3 meters thick throughout much of its area.[9] The ore is mined by continuous borers and transported to the surface by hoist through vertical shafts.

Processing and Products

Sylvinite ores - mixtures of sylvite and halite - are commonly beneficiated by froth flotation in saturated brine solutions. The processing consists of grinding, desliming, flotation and drying circuits.

The ore is crushed using impact crushers and roll mills operating in closed circuit with several sets of screens. The newer wet impact type crushers enable an earlier slime wetting and liberation stage which keep plants cleaner.

Desliming is the next step. The objective is to remove the insolubles which reduce recovery efficiency during flotation. Sized ore in a saturated NaCl-KCl solution is agitated in a series of scrubbers. The fine insolubles are liberated from the sylvite and halite crystals and are separated as a tailing fraction using classifiers and hydroclones.

Deslimed ore is mixed with an amine which acts as a flotation agent and adheres only to the potash particles. Then it is pumped into the flotation cells where agitation with air and additives allows the potash to be floated off as a concentrate, while the halite is pumped to waste.

Fine and coarse feeds are commonly conditioned separately. At this stage, some fine salt is carried over with the rougher concentrate despite high flotation efficiency. One way to eliminate that fine salt is to clean the coarse concentrate by

screening out the fines while fine rougher concentrate is upgraded in a cleaner flotation stage.

A crystallizer circuit is used to give a high purity product by a solution process from several product streams (10-25% of plant product) that cannot be upgraded by physical methods.

Screen bowl centrifuges are used to debrine the crystallizer and flotation product slurries. The debrined materials are dried in rotary or fluidized-bed dryers.

At the end of the drying circuit, a set of screens is used to size the products into the different grades (standard, suspension, coarse). The fourth product, granular, is produced by compaction of standard and suspension material. Crystallizer products are screened separately to produce a white soluble material and a refined material.

The process involves brine recovery circuits to decrease losses of potash.

The different commercial products are used as follows:

- **Standard** and **suspension** are used primarily in granulation plants. They are mixed with given amounts of nitrogen and phosphate, then granulated to give a blended fertilizer.

- **Coarse** and **granular** are involved in bulk blending processes. Standard, coarse and granular can also be used in direct application.

- **Soluble** is used for liquid mixed fertilizers and chemical industry.

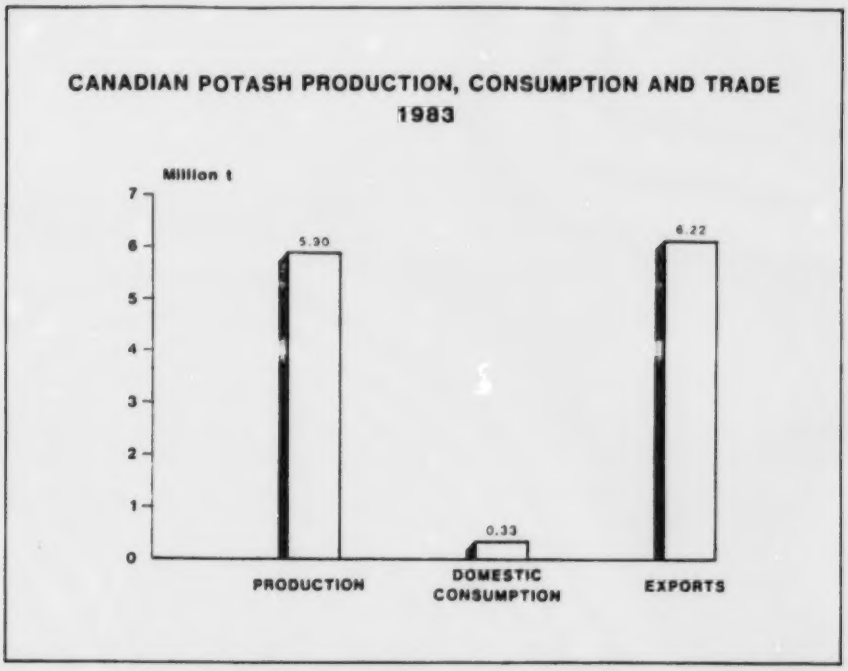
- **Refined KCl** is used in industrial applications.

The Canadian Industry

Potash was first discovered in Canada in the early 1940's while drilling for oil in Saskatchewan. The first potash was shipped in 1959 and Canada became the world's second largest producer in 1968. In 1979, Canada accounted for about 39% of the international potash trade.

Canada exports 95% of its production. About 70% of the exports go to the United States. The production volumes in 1983 are shown in the following diagram.

FIGURE I - Canadian Production Volumes 1983[2]
(in thousand tonnes K_2O equivalent)



Source: Canadian Mining Journal, February 1984.

Location of potash mines and capacity projections are shown in Table 4.

TABLE 4 - Potash Mines - Capacity Projection (000 tonnes K_2O Equivalent)[2]

Company/Location	1982	1983	1984	1985	1986	1987	1988	1989	1990	Remarks
PCS	490	-	-	-	-	-	-	-	-	
- Allan (60%)	490	490	490	655	655	655	655	655	655	Not a firm commitment. Grades: granular, coarse, standard, soluble, suspension and refined.
- Bredenbury	-	-	-	-	655	1310	1960	1960	1960	Mid-1986, earliest taryet.
- Cory	830	830	830	950	1090	1090	1090	1090	1090	Not a firm commitment. Grades: granular, coarse standard, soluble, suspension and retined.
- Esterhazy (25% of IMCC)	585	585	585	585	945	945	945	945	945	Put in abeyance due to crisis. Grades: granular, coarse, standard, soluble, suspension and retined.
- Lanigan	830	830	1285	1740	1740	1740	1740	1740	1740	Grades: granular, coarse and standard.
- Rocanville	1090	1090	1090	1090	1090	1090	1090	1090	1090	Grades: granular, blend, coarse, standard.
CCP: Viscount	815	815	815	815	815	815	815	815	815	Two grades of products: standard, and granular.
Cominco Ltd., Vanscoy	600	655	655	655	655	655	655	655	655	Three grades of products: standard, granular and coarse.
IMCC, Esterhazy	1750	1750	1750	1750	2110	2110	2110	2110	2110	Conjectural - Not a firm commitment.
Kalium Chemicals Belle Plaine	1055	1055	1055	1055	1055	1055	1055	1055	1055	Grades: standard, coarse, granular and fine soluble.
PCA, Saskatoon	440	635	635	635	635	635	635	635	635	
Can. Dev. Corp. Allan (40%)	325	325	325	435	435	435	435	435	435	Not a firm commitment.
Total Saskatchewan	8680	9060	9505	10365	11880	12535	13185	13185	13185	
Denison, N.B.	-	-	100	400	765	765	765	765	765	Company has to make a decision on whether to proceed with production.
PCA, Sussex, N.B.	-	200	400	545	545	545	545	545	545	Expansion after 1985 possible.
IMCC, Man.	-	-	-	-	-	100	545	1090	1090	Conjectural start-up between 1987 and 1989.
Total Canada	8680	9260	10005	11310	13190	13945	15040	15835	16085	

The breakdown of the Canadian potash production by product in 1981 was:

TABLE 5 - 1981 Canada, Potash Production Breakdown by Product

Product	%
Coarse	36.6
Standard (includes suspension)	28.5
Granular	23.9
Soluble	10
Refined KCl	1

Source: Potash and Phosphate Institute

The typical chemical analysis of processed muriate of potash (KCl) as it is marketed in Canada is shown in Table 6.

TABLE 6 - Chemical Analysis of Muriate of Potash[3]

Compound	Percent
K	50.5
Mg	0.17
Ca	0.02
Na	1.05
Cl	47.86
SO_4	0.04
Insoluble	0.30

Potash is graded chemically according to a standard known as "potassium oxide equivalent (K_2O)". For many years it was thought that the potassium oxide was the key factor in fertilizers and, although this is no longer believed, it remains a unit of measure in potash trade (1.0% K is equivalent to 1.2046% K_2O).

Potash is also classified according to particle size. Products with higher potash grades and coarser particles are more desirable. The grade of pure muriate is 63.2% K_2O equivalent.

Potash Corporation of Saskatchewan, Cory Division, manufactures basically two types of products; floated "pink" and crystallized "white". The pink products are classified by screening into four grades. The crystallized products are "soluble" and "refined". The soluble product is derived by treating overflow brines chiefly from tails and slimes thickeners. The refined product is 99.95% KCl and is manufactured by subjecting a portion of soluble product to a second crystallization process.

The characteristics of the different commercial potash products are shown in Table 7.

TABLE 7 - Commercial Potash Products[7]

TREATMENT	PRODUCT	K_2O CONTENT %	APPROXIMATE PARTICLE SIZE RANGE mm
Flotation (Pink)	Granular	61	3.4-0.8
	Coarse	61	2.4-0.6
	Standard	61.51	1.7-0.2
Crystallization (White)	Soluble	62	0.4-0.15
	Suspension	61	0.4-0.075
	Refined KCl	63	fine

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REFERENCES

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THE SILICA INDUSTRY

ENERGY CONSERVATION IN THE INDUSTRIAL
MINERALS PROCESSING SECTOR - COMMINUTION

(Phase I - Plant Studies)

Work on this Project was conducted by
Canada Cement Lafarge Ltd.,
under the auspices of the
Canada Centre for Mineral and Energy
Technology; Energy, Mines and Resources, Canada

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DSS Contract Serial Number: OSQ82-00228

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APPENDIX - Industry Review

1. General Information
2. Product Characteristics
3. Quality Criteria

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1. INTRODUCTION

Under the general title of "Energy Conservation in the Industrial Minerals Processing Sector - Comminution", Phase I of the project deals with plant studies to develop a data base. Phases II and III will attempt to reduce the amount of energy used in comminution.

The plant studies aim at establishing the comminution requirements and classification characteristics for some industrial minerals. Product specification must be considered. The plant studies involve the description of typical operations for each industrial mineral and the compilation of data among which are included the following parameters:

- Operating conditions
- Production rate, flowrates and material balance
- Particle size distributions
- Direct energy consumptions

The data on these parameters is compiled at each comminution stage and the variability of measurements reported.

The report introduces briefly the Canadian silica industry. A description follows of typical comminution processes used in the silica industry. Power level estimates and energy consumption data are then reported and discussed. Conclusions end the body of the report.

For readers who are unfamiliar with the silica industry, an appendix entitled "Industry Review" is added.

The Canadian silica industry is mainly based in Quebec and Ontario with about two thirds of the production being generated in these two provinces. Some production is done in every province, except Prince Edward Island.

Historically, consumption has always been greater than production and imports cover generally about 30% of consumers' needs. Exports are small, representing around 5% of imports. Typically, the annual consumption is over 3 million tonnes while production is over 2 million tonnes.

The main consuming industries for silica are as follows:

- The ferrous industry using foundry sand.
- The glass making industry using silica.
- The non-ferrous metallurgical industry using lump silica as smelter flux.
- The ceramic industry using finely ground silex grade silica.
- The filler industry using extremely finely ground silica.

The first three industries consume up to 75% of total consumption in relatively equal shares while the rest is distributed over a multitude of uses, the major ones being cement making, concrete products, abrasives, silicon and silicon alloys, ceramic products, fillers and extenders.

Canada imports mainly high-grade silica for use in glass manufacturing, and round-shaped sand suitable for foundry castings. These imports come almost entirely from the United States where many producers are well located, close to the border, and are advantaged by low transportation costs and very pure deposits requiring only simple, low-cost mining and processing.

For more details, see Appendix.

3.1 Silica Process Flow

A typical silica processing flow sheet for a quartzite ore is shown in Figure I. It consists of a three-stage crushing circuit for ore preparation, a primary grinding (rod mill) and classification circuit to produce various sizes of silica sand, a flotation circuit to produce a flint grade and fine grinding circuit (pebble mill) to produce 75 and 45 μm silex grade products.

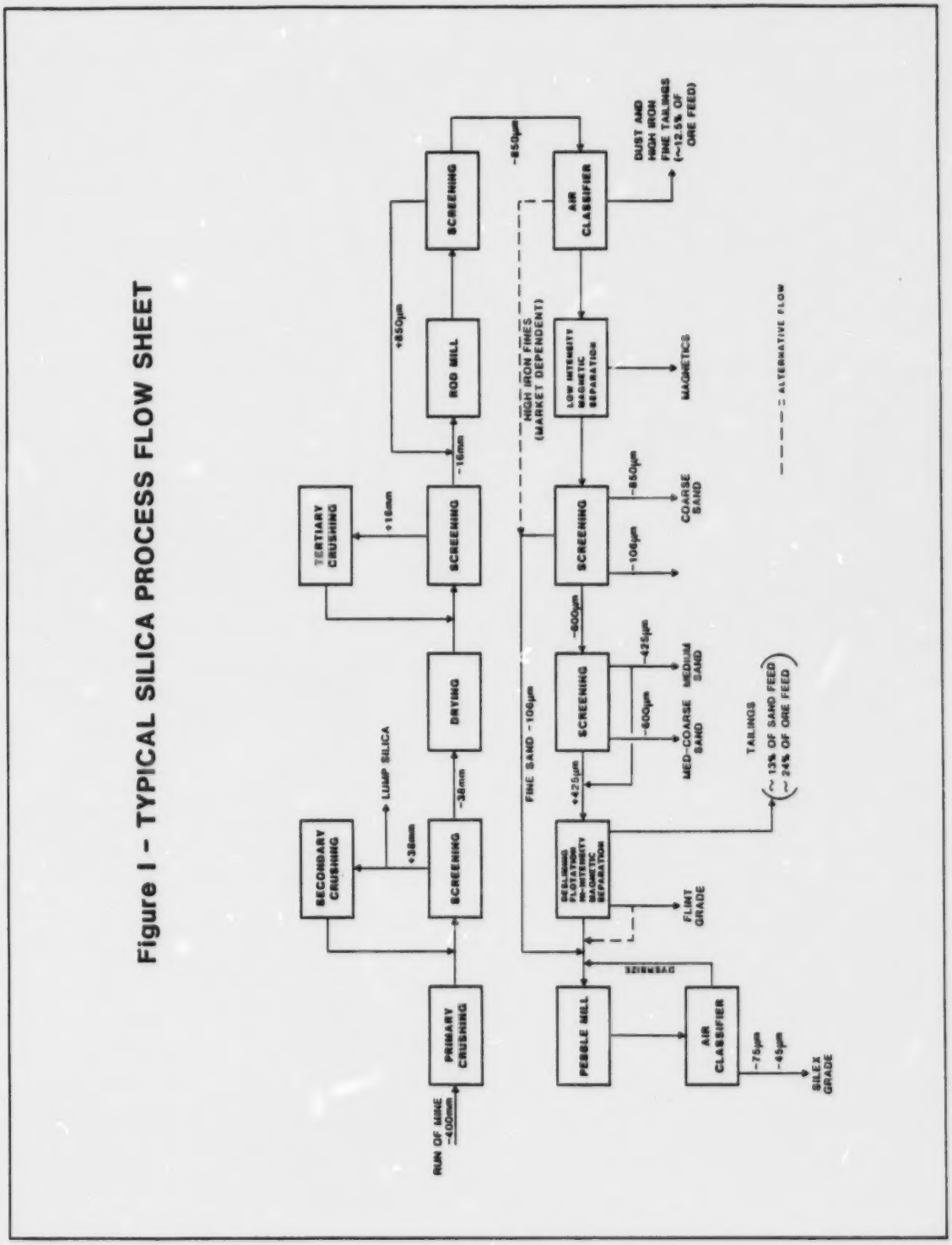
At given points of the flow sheet, equipment such as screens, air classifiers and low and high intensity magnetic separators are used to size and remove iron-containing particles. The flint grade requiring desliming and flotation is not detailed because no further comminution takes place in generating this product.

3.2 Ore Crushing and Drying

Figure II illustrates a typical ore crushing and drying circuit. A typical list of equipment with motor electrical data is given in Table 1. Estimated average power demand values are immediately added as no field work and actual plant measurements could be made in an operating environment.

The crushing circuit is usually located at the quarry site and operates on one shift a day, five days a week. The average production rate for the circuit envisaged here is estimated at 135 t/h.

Figure I - TYPICAL SILICA PROCESS FLOW SHEET



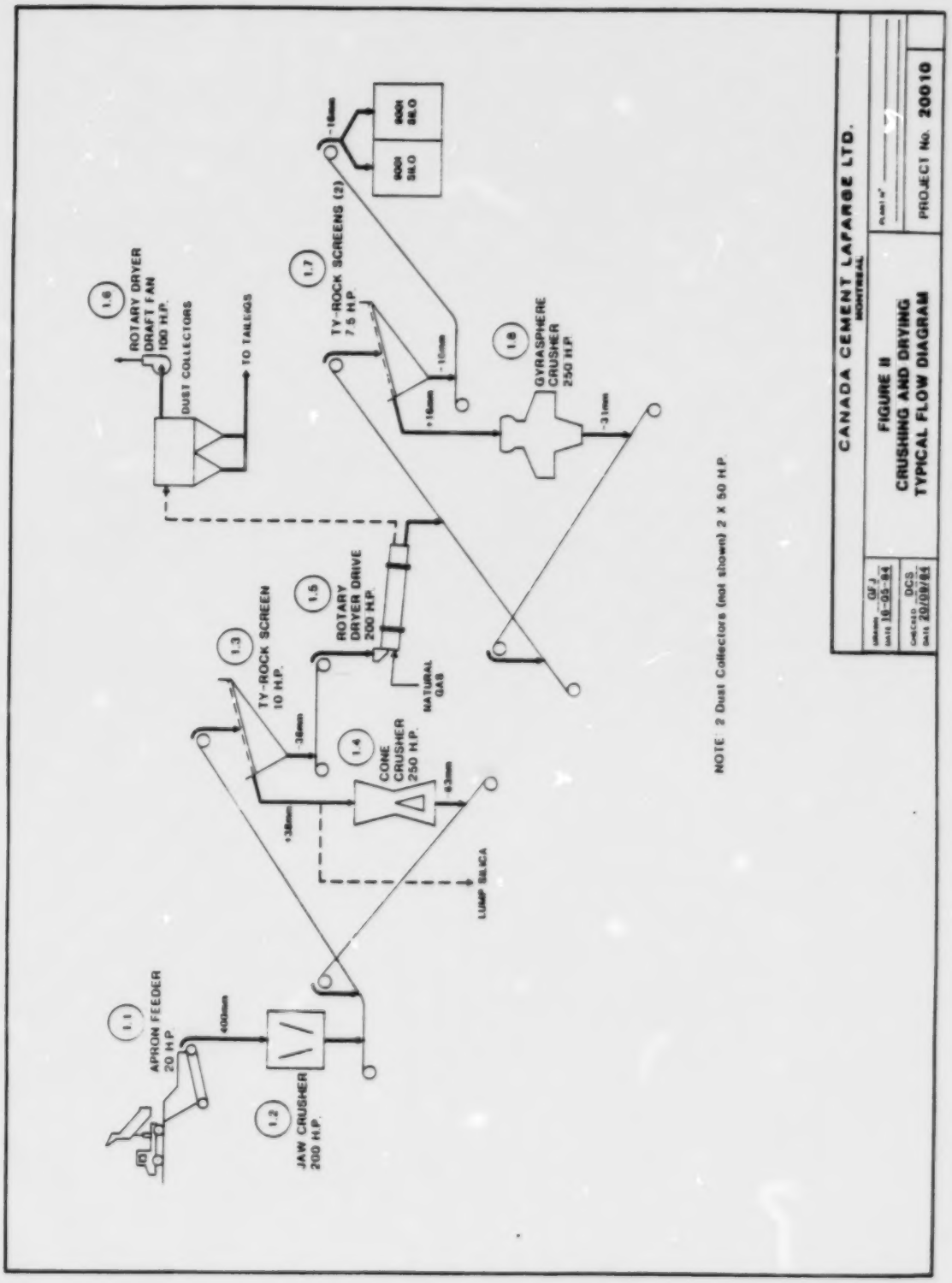

1.1
APRON FEEDER
20 H.P.
400mm
1.2
JAW CRUSHER
200 H.P.
1.3
TY-ROCK SCREEN
10 H.P.
-38mm
+38mm
1.4
CONE
CRUSHER
250 H.P.
-13mm
LUMP SILICA
1.5
ROTARY
DRYER DRIVE
200 H.P.
NATURAL
GAS
1.6
ROTARY DRYER
DRAFT FAN
100 H.P.
DUST COLLECTORS
TO TAILINGS
1.7
TY-ROCK SCREENS (2)
7.5 H.P.
-16mm
+16mm
-16mm
BOOM
38.0
BOOM
38.0
1.8
GYRASPHERE
CRUSHER
250 H.P.
-31mm
NOTE: 2 Dust Collectors (not shown) 2 X 50 H.P.
CANADA CEMENT LAFARGE LTD.
MONTREAL
FIGURE II
CRUSHING AND DRYING
TYPICAL FLOW DIAGRAM
PROJECT No. 20010
DRAWN GF J
DATE 10-05-84
CHECKED DCS
DATE 20/09/84

TABLE 1 - Crushing and Drying - Typical Equipment List
Electrical Data and Estimated Power Demand

No.	EQUIPMENT	MOTOR* HP	POWER DEMAND kW AVG.
1.1	Apron Feeder	20	8
1.2	Jaw Crusher - 4160V	200	50
1.3	Ty-Rock Screen - 5' x 12'	10	4
1.4	5½ ft Cone Crusher - 4160V	250	100
1.5	Rotary Dryer Drive - 4160V	200	75
1.6	Rotary Dryer Draft Fan	100	58
1.7	Ty-Rock Screen - 4' x 12' (2)	7	3
1.8	Gyrasphere Crusher - 4160V	250	150
1.9	Crushing Plant Dust Collector	50	29
1.10	Screening Plant Dust Collector	50	33

* All motors 550V unless noted.

An apron feeder feeds minus 400 mm ore to a primary jaw crusher powered by a 200 HP motor. The product is screened with the undersize minus 38 mm fraction going to the dryer. The oversize is reduced to minus 63 mm in a secondary cone crusher closing the circuit with the 38 mm screen. A 250 HP motor powers the cone crusher. The secondary crusher product joins with the primary crusher product, creating an estimated combined flow of 225 t/h and a circulating load of about 60-65%.

The installed power for the dryer drive and the draft fan totals 300 HP. After drying, the ore proceeds to a second closed circuit consisting of two screens and a gyrasphere crusher, the latter being powered by a 250 HP motor. The screens extract the minus 16 mm finished product from the combined dryer discharge and circulating load. The plus 16 mm oversize fraction is reduced to minus 31 mm by the tertiary gyrasphere crusher. The circulating flow would be 270 t/h.

The crushing circuit is equipped with two dust collectors, each with a 50 HP fan.

3.3 Primary Grinding and Classification

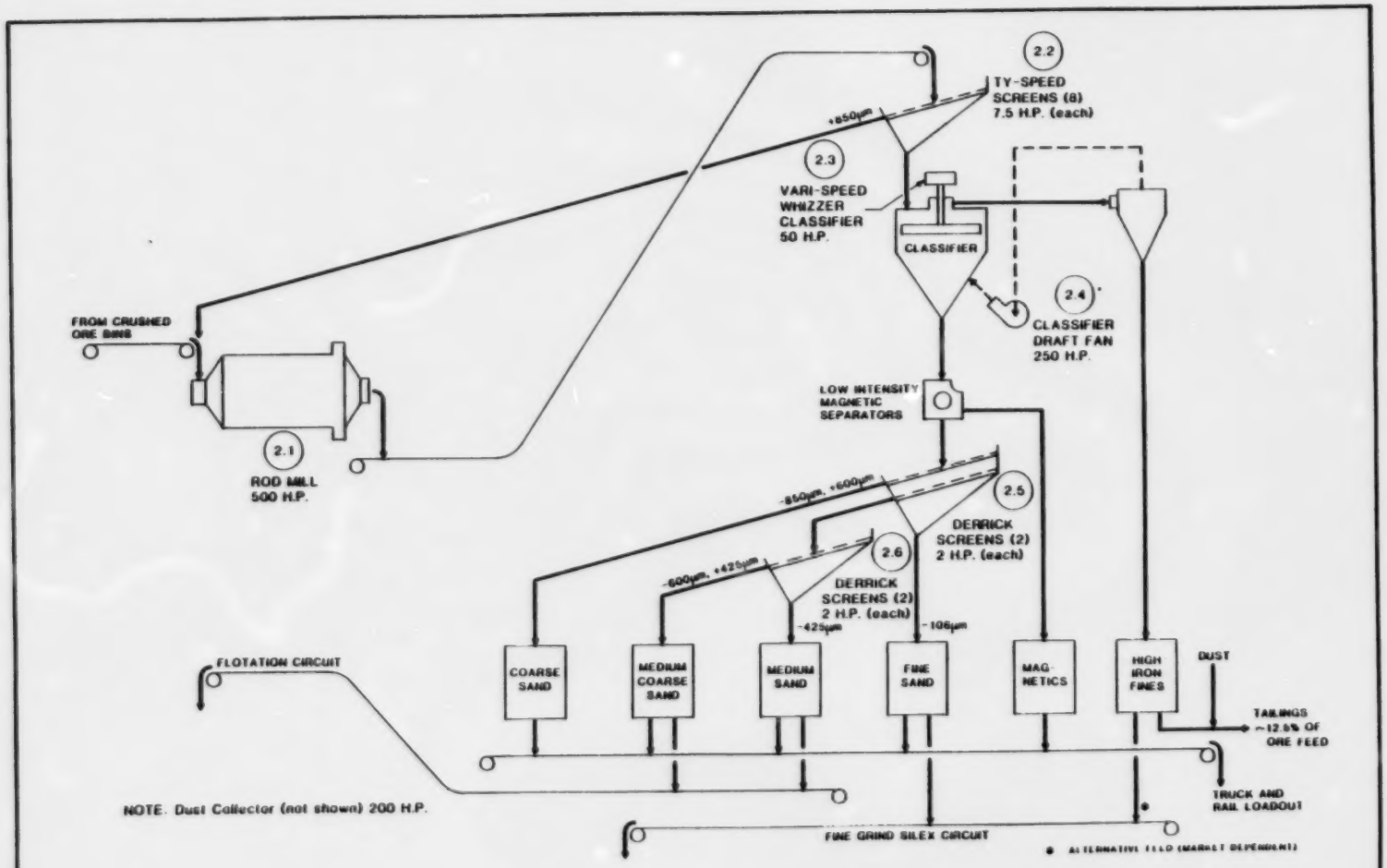
Primary grinding is effected in a rod mill circuit closed by a series of screens with an 850 μm aperture. The ground product is upgraded by removing abraded iron by magnetic air classification and separation before final screen classification into various size fractions ranging from 850 to 106 μm. A typical chemical specification for glass sand manufacture would be about 99.6% SiO_2, 0.15% Al_2O_3, 0.03% Fe_2O_3 and consistently low CaO and MgO.

A typical process flow sheet is depicted in Figure III and a typical equipment list with motor electrical data is given in Table 2. Estimated power demand values are shown.

TABLE 2 - Primary Grinding and Classification
- Typical Equipment List: Electrical Data & Estimated Power Demand

No.	EQUIPMENT	MOTOR* HP	POWER DEMAND kW AVG.
2.1	Rod Mill - 11.5' x 14' - 4160V	500	300
2.2	Ty-Speed Screen - 4' x 10' (8)	7	3
2.3	Vari-Speed Whizzer Class. - 500 DC	50	25
2.4	Classifier Draft Fan	250	170
2.5	Derrick Screen - 4' x 10' (2)	2	1
2.6	Derrick Screen - 4' x 10' (2)	2	1
2.7	Dust Collector	200	120

* All motors 550V unless noted.



CANADA CEMENT LAFARGE LTD. MONTREAL		
DRAWN GFJ DATE 15-05-84	FIGURE III PRIMARY GRINDING & CLASSIFICATION TYPICAL FLOW DIAGRAM	PLANT N°
CHECKED DCS DATE 20/09/84		PROJECT No. 20010

The circuit operates 24 hours a day and the average sand production rate, including saleable magnetics, is estimated at 35 t/h from an ore feed rate of 40 t/h, thus generating about 12.5% tailings of high iron fines and dust. Depending on market requirements, the iron fines are sometimes up-graded by high intensity magnetic separation, or finely ground and classified, or sold without further treatment.

An 11.5' diameter by 14' grate discharge rod mill, powered by 500 HP, is used to generate 40 t/h of minus 850 µm product. The circulating load is estimated at 200%. The ground product is then fed to a vari-speed whizzer classifier having an external draft generated by a 250 HP fan to remove the fines containing up to 0.6% Fe_2O_3. Low intensity magnetic separators complete the sand up-grading by recovering some of the abraded iron added during milling with steel rods.

Ready for classification, the sand is screened on two double-deck screens having top and bottom apertures of 600 and 106 µm, respectively. The oversize and undersize make two sand products, coarse (-850, +600 µm) and fine (-106 µm), while the mid or medium fraction is separated by a set of two single-deck screens (425 µm aperture) in two other sand products, medium-coarse (-600, +425 µm) and medium (-425, +106 µm). Dust control is effected by the use of a collector equipped with a 200 HP fan.

These sand products are sold as is, or can be processed further, the medium-coarse and medium sand going to flotation to produce the higher purity flint grade, and the fine sand, to the pebble mill circuits to produce either 75 or 45 µm silex grades.

3.4 Flotation

A sized sand can be upgraded to flint grade, i.e., containing less than 0.02% Fe_2O_3, by processing through a circuit illustrated in Figure IV and comprising three stages of beneficiation: attrition scrubbing, flotation and magnetic separation.

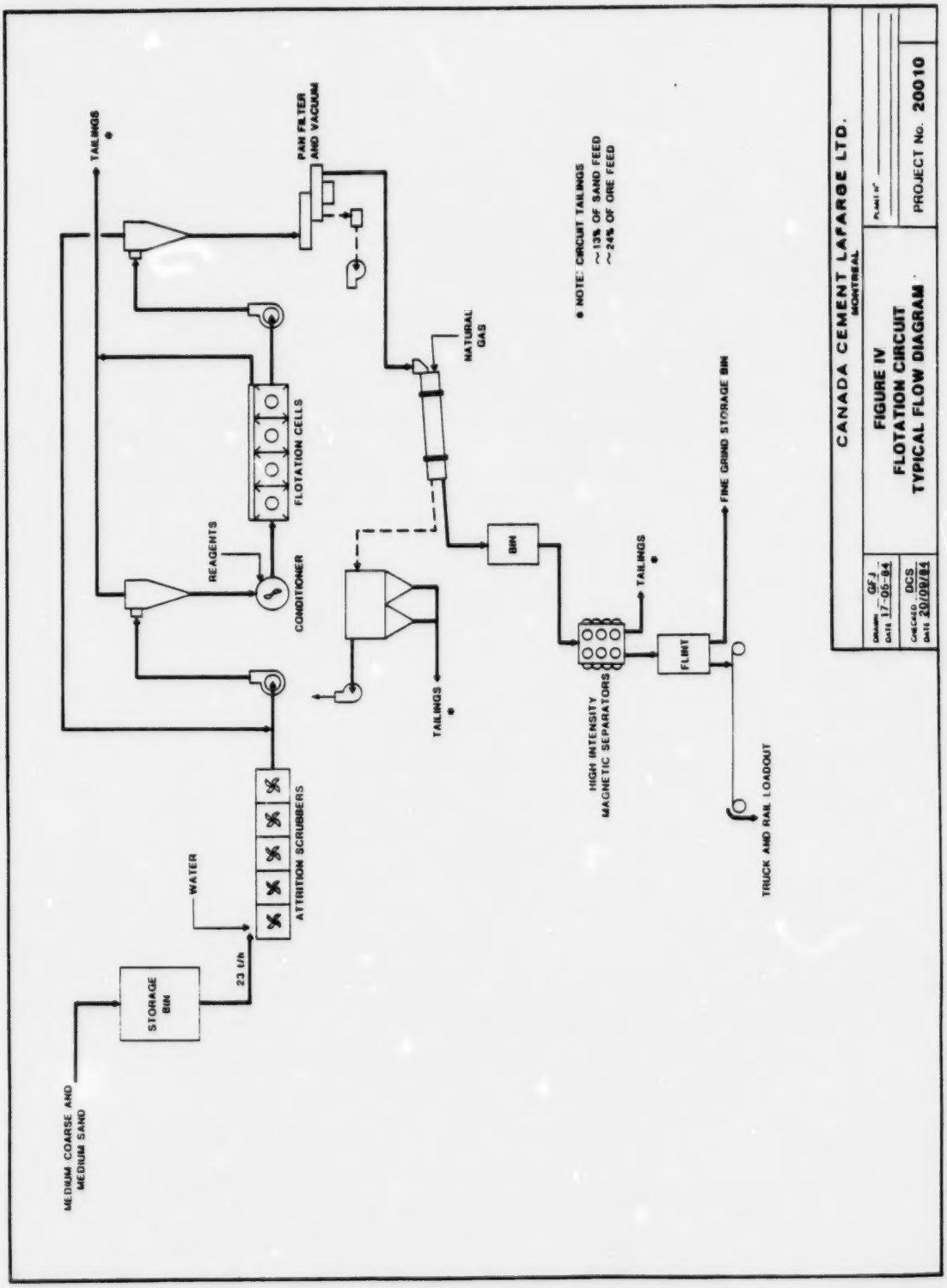
Attrition scrubbing releases the clay minerals from the silica grains and these are separated using a hydrocyclone. The underflow fraction is further treated by flotation to remove iron oxide minerals, then filtered, dried and processed by high intensity magnetic separators.

Tailings from slimes, flotation and magnetic separation may represent about 13% of sand feed, or 24% of equivalent ore feed. The flint sand thus obtained can be marketed as is, or can be ground further in a pebble mill to produce a higher quality silica flour.

3.5 Fine Grinding

The 75 and 45 μm silex grade silica flours are produced in two pebble mills in closed circuit with a variable speed Gyrotor classifier.

Figure V illustrates a typical process flow diagram and Table 3 gives a typical equipment list, including motor electrical data and estimated power demand values.


MEDIUM COARSE AND MEDIUM SAND
STORAGE BIN
23 t/h
WATER
ATTRITION SCRUBBERS
REAGENTS
CONDITIONER
FLOTATION CELLS
TAILINGS
PAN FILTER AND VACUUM
NATURAL GAS
BIN
TAILINGS
HIGH INTENSITY MAGNETIC SEPARATORS
TAILINGS
FLINT
FINE GRIND STORAGE BIN
TRUCK AND RAIL LOADOUT
* NOTE: CIRCUIT TAILINGS
~13% OF SAND FEED
~24% OF ORE FEED
CANADA CEMENT LAFARGE LTD.
MONTREAL
FIGURE IV
FLOTATION CIRCUIT
TYPICAL FLOW DIAGRAM
PROJECT No. 20010
DRAWN GFJ DATE 17-05-84
CHECKED DCS DATE 20/09/84

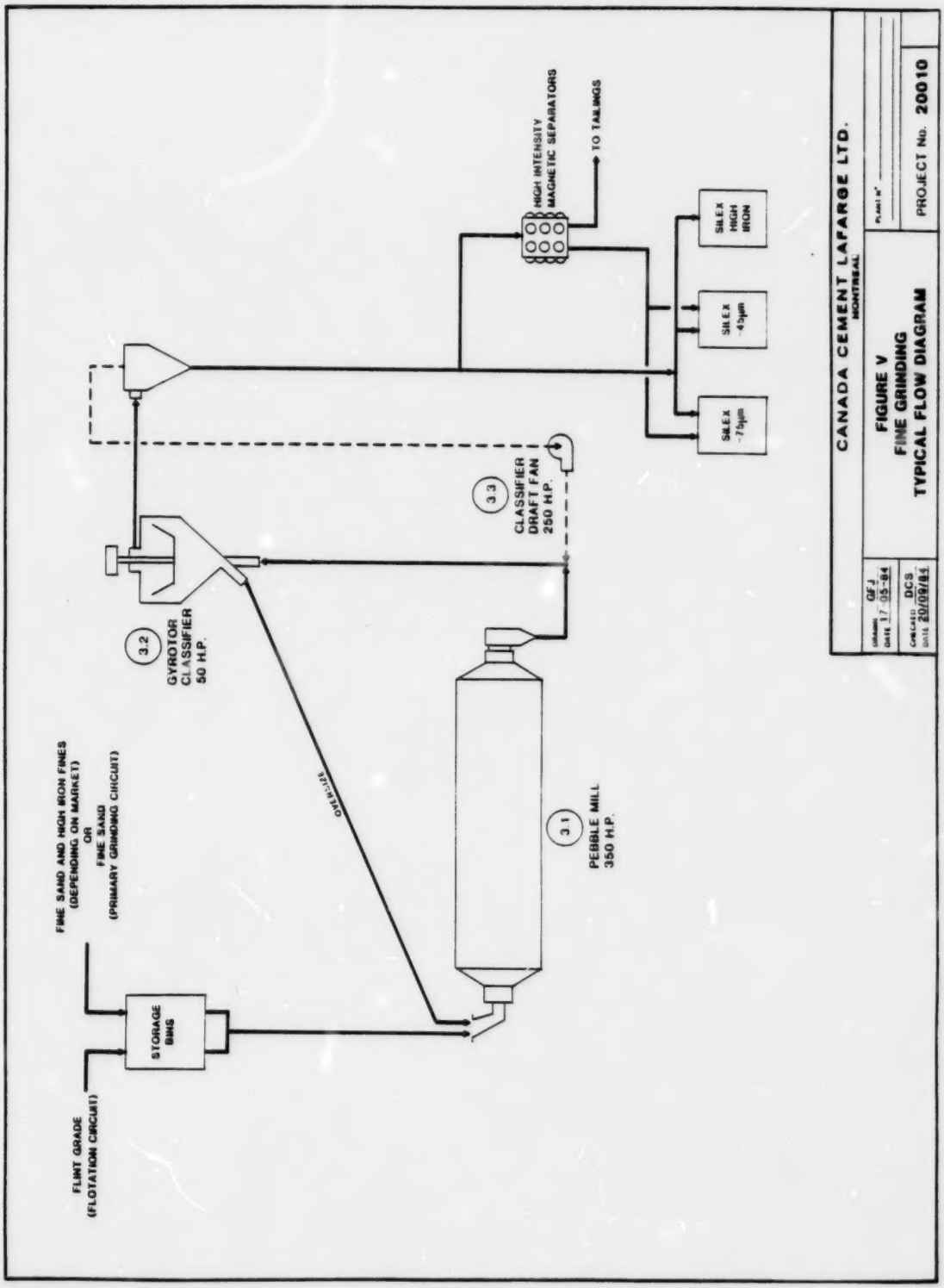

FLINT GRADE
(FLOTATION CIRCUIT)
FINE SAND AND HIGH IRON FINES
(DEPENDING ON MARKET)
OR
FINE SAND
(PRIMARY GRINDING CIRCUIT)
STORAGE BINS
3.1
PEBBLE MILL
350 H.P.
OVERSIZE
3.2
GYROTOR
CLASSIFIER
50 H.P.
3.3
CLASSIFIER
DRAFT FAN
250 H.P.
HIGH INTENSITY
MAGNETIC SEPARATORS
TO TAILINGS
SILEX
-7½µm
SILEX
-4µm
SILEX
HIGH
IRON
CANADA CEMENT LAFARGE LTD.
MONTREAL
FIGURE V
FINE GRINDING
TYPICAL FLOW DIAGRAM
PROJECT No. 20010

TABLE 3 - Fine Grinding - Typical Equipment List: Electrical Data and Estimated Power Demand

No.	EQUIPMENT	MOTOR* HP	POWER DEMAND kW AVG.
3.1	Pebble Mill - 7' x 26' - 4160V	350	200
3.2	Gyrotor Classifier - 500 DC	50	35
3.3	Classifier Draft Fan - 575V	250	170

* All motors 550V unless noted

Fine sand (-106 μm) is the usual feed for the 7' diameter by 26' pebble mills which are driven by 350 HP motors. The mills have 45% of their volume loaded by high density alumina pebbles. The mill discharge is air swept to the classifier in a closed airflow circuit generated by a 250 HP draft fan. Variable speed selector blades (Gyrotor design) allow a fine control of the cut point. The oversize is feed back to the mill, creating a circulating load up to 400%. A cyclone extracts the fines that may be further treated in a high intensity magnetic separator for final iron removal.

Production rates of the pebble mill system vary from 4.5 t/h on the 75 μm silex grade to 2.7 t/h on the 45 μm silex grade.

The energy consumption data have been calculated on the basis of estimated power demand values and production rates given in the preceding section.

Results are grouped according to circuit operation. Products average specific energy consumption is also reported in a cumulative basis. No particle size distribution data could be obtained and no grindability testing was done, but a typical Bond index value is given.

4.1 Ore Crushing and Drying

4.11 Power Demand Estimates

The crushers average power demand totals 300 kW (see Table 1) representing a loading of about 55-60% of installed power. The estimates have been based on typical average loading for the respective crusher type, ranging from 33% on the jaw crusher to 80% on the gyrasphere crusher. Besides the dryer draft fan, two dust collectors, one for crushing and the other for screening, draw 60 kW together; their power demand has been estimated on 80% motor loading. The dryer drive and draft fan motor loads have been estimated at 50% and 75%, respectively.

4.12 Specific Energy Consumption

Table 4 gives the specific energy consumption for crushing and drying and shows that comminution represents 58% of the total. Although this proportion is typical of crushing circuits, at 2 kWh/t, the consumption for silica ore crushing is higher than for other minerals (typically around 1 kWh/t).

TABLE 4 - Silica Ore Crushing and Drying
Specific Power Consumption

	kWh/tonne	%
Comminution	2	50
Auxiliaries	2	50
Total	4	100

A complete distribution of consumption is given in Table 5. Drying accounts for a large portion of total consumption and equals 1 kWh/t when expressed in specific terms. Dust collection does not represent a consumption item as important as seen for other minerals.

TABLE 5 - Silica Ore Crushing and Drying
Distribution of Consumption

	%
Crushing	58
Ore Feeding	2
Screening	2
Drying	26
Dust Collection	12

4.2 Primary Grinding and Classification

4.21 Power Demand Estimates

Grinding is conducted by a rod mill drawing an average demand of 300 kW, equal to 80% of installed capacity. Classification is a major source of energy consumption, particularly on account of the whizzer classifier draft fan which is highly loaded at more than 90% of nominal power. Power demand for dust collection has been estimated on 80% motor loading.

4.22 Specific Energy Consumption

Table 6 gives the circuit specific energy consumption. Comminution has a smaller share of total consumption because of the increased importance taken by classification and dust collection (Table 7).

TABLE 6 - Primary Grinding and Classification Specific Power Consumption

	kWh/tonne	%
Comminution	8.6	46
Auxiliaries	10.0	54
Total	18.6	100

TABLE 7 - Primary Grinding and Classification Distribution of Consumption

	%
Grinding	46
Classification	35
Dust Collection	19

4.3 Fine Grinding

4.31 Power Demand Estimates

The fine grinding circuit is a simpler one involving only three motors, two being large power consumers. The pebble mill runs on average at just over 75% of nominal power. The classifier draft fan is again highly loaded at about 90% of nominal power. The gyrotor classifier is running at almost full power.

4.32 Grindability

A Bond Work Index value of 26 kWh/ton is believed to be

representative for a typical quartzite silica ore.

4.33 Specific Energy Consumption

Energy consumed in the fine grinding circuits is distributed equally between the pebble mills and their classifiers. The capacity of the circuit is limited by the size of the mill fan and classifier and their motors. Finer products result in higher circulating loads, lower feed rates and proportionately higher unit energy consumption. This is shown on Table 8.

TABLE 8 - Silex Grade Fine Grinding
Specific Power Consumption

Product	Grinding (kWh/tonne)	Auxiliaries (kWh/tonne)	Total (kWh/ tonne)	Comminution Consumption (%)
Silex 200	44	46	90	49
Silex 325	74	76	150	49

4.4 Products Specific Energy Consumption

An average specific energy consumption for the various silica products is presented in Table 9. These values are cumulative and take into account the product yield in the various circuits. For instance, the sand grades include the specific consumption for primary grinding and classification plus that for ore crushing and drying, corrected for the high iron fines lost to tailings. The flint grade specific consumption is calculated to take into account tailings in the flotation and the primary grinding and classification circuits. For silex grades, a 50:50 sand and flint feed was selected to calculate the cumulative specific consumption.

TABLE 9 - Silica Products Cumulative Consumption
Average Specific Power Consumption

Product	Comminution (kWh/tonne)	Auxiliaries (kWh/tonne)	Total (kWh/ tonne)	Comminution Consumption (%)
Sand Grades	11	12	23	48
Flint Grade	13	13	26	50
Silex 200	56	59	115	49
Silex 325	86	89	175	49

For all products, the specific energy consumption values determined for comminution are high and can be explained by the high Work Index value of quartzite. In this regard, it is noteworthy that the silex 200 comminution consumption (56 kWh/t) is more than double the Bond Work Index value. This fact may represent a subject worthy of further study: one may wonder if the energy consumption of an industrial mill system is greater than that of the Bond test mill on account of the classification inefficiency, the high circulating load, the material transport properties through the mill or a combination of the preceding factors.

In examining the total specific consumption, energy is seen to be shared equally between comminution and auxiliaries for all types of products. This may be peculiar to silica processing. Compared to other minerals previously investigated, the specific energy consumptions are high and put silica recovered from quartzite deposits in the higher energy consumers.

The energy consumption for comminution of quartzite ores for the production of silica grade is high relative to other minerals studied. The high consumption is related to the hardness of the ore as measured by the Bond Work Index and the energy consumed by auxiliary equipment for dust control and air classification.

Product specific energy consumptions range from 23 and 26 kWh/tonne for sand grade and flint grade, respectively, to 115 and 175 kWh/tonne for Silex 200 and Silex 325, respectively. In each case, the energy consumption for auxiliaries accounts for half of the total consumption.

The high energy consumption on a product basis results mainly from high circuit energy consumption and, partly, from beneficiation inducing the wastage of ground material when making sand and flint grades.

The energy cost for comminution and associated operations is believed to account for about 40% of electrical costs which, in turn, represent about 12% of total operating costs.

The savings potential would appear to lie mainly in the area of auxiliaries which impact so greatly the total consumption for comminution and associated operations. This remark is referring specifically to the use of external draft-type classifiers in the removal of high iron fines in the sand circuit and in the pebble mill circuits for silex grade production.

APPENDIX

INDUSTRY REVIEW

GENERAL INFORMATION

The Mineral and its Processing

Silica occurs in abundance on the earth's surface in a variety of forms. It is an industrial mineral with which Canada is particularly well endowed. It occurs chiefly as quartz, but is found in many forms including sand, sandstone, quartzite and vein quartz.[1]

The term "silica" refers to silicon dioxide (SiO_2) in all its crystalline, amorphous and hydrated or hydroxylated forms.

Silica deposits are mostly of detrital origin and are composed essentially of the mineral quartz, which was originally derived through the weathering of a quartz-bearing igneous rock, such as granite. Hence, the deposits are often composed of the constituent minerals of granite: quartz, feldspar, mica and hornblende, with possible accessories such as zircon, tourmaline, garnet, magnetite and pyrite. The result is an impure, low silica sand. Workable deposits of silica are of four types: unconsolidated silica sand, sandstone, quartzite, and pegmatitic quartz.[2]

Canadian sand deposits are often of glacial origin. Sands derived from glacial debris usually consist of extremely heterogenous material. For this reason, high purity silica deposits are scarce. Such glacial formed deposits can furnish large tonnages of sand suitable for silica flux, foundry sand, and other uses not requiring a high degree of purity.[2]

Sandstones are the most widely used sources of silica sand. They consist of aggregates of sand grains bonded by a mineral cement, usually silica or calcareous material. When the quartz grains of a sandstone are recrystallized by metamorphism, the rock becomes a quartzite and loses the granular texture of the

original sandstone. During the mining of many granite pegmatites for feldspar, considerable tonnages of quartz must also be mined which may be sold as lump silica for use as flux.[2]

Silica occurs as the mineral quartz in a variety of rocks and unconsolidated sediments. Although it is one of the most abundant minerals, making up an estimated 12 per cent of the earth's crust, commercial sources of silica are presently restricted to uncommonly pure deposits. Further, because of its low unit value, an economically viable deposit should normally be mineable by low cost, open pit methods, and, ideally, be located close to consuming areas in order to minimize transportation costs.[3] Deposits of lower purity are being investigated as possible sources of high grade sand, if beneficiation costs can be minimized.[4]

The principal uses for silica are: as the chief constituent in glass, as metallurgical flux, in the manufacture of silicon carbide, as silicon ore for ferrosilicon, as foundry sand for metal castings, in sand blasting, and as filler material in tile, asbestos cement pipe, concrete and bricks.[3]

Mining can be done by underground or open pit methods, depending on the location of the deposit and cost. Loading is done by shovel and then the material is hauled by truck or rail to the plant. Further processing steps depend on how consolidated and how pure is the stone. In general, primary crushing is done by jaw, gyratory, cone, or roll crushers. Where the material is of poor coherence, an impact crusher of the hammer mill type will reduce much of the rock to a sand product in one stage. Otherwise, final reduction to grain size, is accomplished with one of several types of crushers/grinders such as: ring-roll, roller, ball, or rod mills (to 600 μm).[2]

Although normally performed dry, reduction of sandstone may also be achieved by wet processing. When wet milling is employed, the cost of drying, particularly in the fine sizes, will be appreciable.[2]

Where fine grinding is necessary to produce a sand or flour product, dust becomes a serious problem. Air classification is employed in a dry milling circuit. In between steps, the desired size product is removed by screening following each pass.[2]

Washing and scrubbing may be done at various stages to remove fines and some impurities, surface coatings, etc. Where silica sand is beneficiated by washing, hydraulic classification is frequently used.[2]

Other steps to remove impurities include: flotation, magnetic or electrostatic separation, and acid leaching.[2,4]

The Canadian Industry

Silica deposits have been developed in virtually every province. Table 1 gives a breakdown of production by province and by use for recent years. While, historically, Ontario produces the highest tonnage of silica sand, Quebec produces more of the higher-value, high-purity sand, thus reporting a greater value of production in spite of lower volumes. Exceptionally, in 1982, the volume in Quebec was larger than that in Ontario, due to a drastic reduction in that province caused by the recessionary slowdown, particularly in the use as smelter flux in the nickel ore processing industry.

TABLE 1 - Canada, Silica Production 1981 and 1982[3]

PRODUCTION, QUARTZ AND SILICA SAND	1981 (000t)	1981 ($000)	1982P (000t)	1982P ($000)
By province				
Quebec	694	12,950	706	13,781
Ontario	901	10,969	482	8,292
Alberta	..	3,173	..	3,088
Manitoba	198	2,284	164	2,688
Nova Scotia	..	2,334	..	1,401
New Brunswick	..	1,000	..	1,400
Saskatchewan	142	1,169	97	1,049
Newfoundland	..	768	..	1,632
British Columbia	..	46	..	36
	2 238	34,693	1 797	33,367
By use				
Glass and fiberglass	489	12,542	..	..
Flux	837	4,054	..	..
Ferrosilicon	339	3,193	..	..
Other uses[1]	573	14,904	..	..
	2 238	34,693	1 797	33,367

Approximately 40% of silica produced in Canada is low-value lump and sand consumed as metallurgical flux. High-quality silica sand suitable for the manufacture of glass is produced by two companies in Canada. Indusmin Ltd., the largest, operates beneficiation plants in southern Ontario and Quebec. Steel Brothers of Canada Ltd. quarries high-grade silica sandstone on Black Island in lake Winnipeg and processes the material at Selkirk, Manitoba (see Table 4 for a list of major Canadian producers).[3]

Canada imports high-grade silica sand for use in glass manufacturing, and sand suitable for foundry castings, silex and crystallized quartz and silica brick.[3] These imports concern mainly silica sand and come essentially from the United States. Table 2 gives the evolution of silica production, trade and consumption during the last decade. The data show the irregularity of consumption during this period having a direct impact on the volume of production while the level of imports generally remained stable. Imports account for about 30% of consumption, exports concern quartzite and are small relative to imports. The data for 1982 show the large decrease in both production and imports reflecting the downturn of the Canadian economy.

TABLE 2 - Canada, Silica Production and Trade, 1970, 1975, 1978-82[3]

(tonnes)

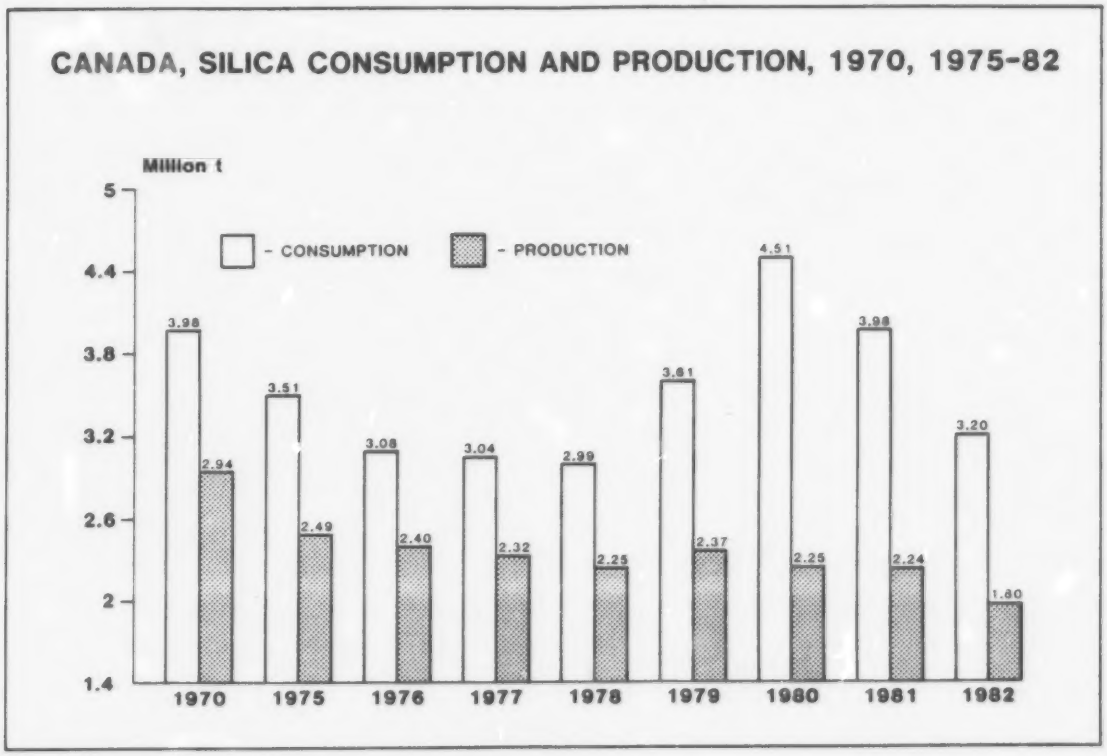
PRODUCTION		IMPORTS			EXPORTS	CONSUMPTION
Year	Quartz & Silica Sand	Silica Sand	Silex or Chrystallized Quartz	Firebrick & Similar Shapes	Quartzite	Quartz & Silica Sand
1970	2 937 498	1 176 199	186	2 020	58 917	3 979 305
1975	2 491 715	1 044 160	1 550	18 818	39 977	3 510 818
1978	2 245 136	1 242 444	1 955	6 948	67 775	2 987 736
1979	2 368 497	1 651 890	1 259	4 896	60 823	3 611 815r
1980	2 252 000	1 200 237	281	4 775	63 166	4 512 637
1981	2 238 000	1 142 880	251	13 762	119 347	3 983 751
1982p	1 797 000	788 768	241	2 984	65 333	..

p Preliminary; .. Not available; r Revised.

The trend of silica consumption and production during the last decade has been on the decrease; this fact is best illustrated by Figure I.

FIGURE I - Canada, Silica Consumption and Production Volumes 1970, 1975-82[3]

(in million tonnes)



Source: Canadian Minerals Yearbook 1982, EMR Canada.

Although the downward trend on consumption was reversed from 1979 and onwards, the production has not followed the same way. In 1982, the production declined substantially (see Table 2).

A typical breakdown of consumption by major industries can be seen in Table 3.

TABLE 3 - Canada, Estimated Consumption of Silica by Industries, 1980 and 1981[3]

	1980	1981
Foundry sand	1 366 152[r]	1 085 481
Glass manufacture (including glass fibre)	968 019	951 442
Smelter flux[1]	1 192 868[r]	837 203
Refractory brick mixes, cements	512 416	359 163
Artificial abrasives	130 461	125 706
Metallurgical	67 812	143 447
Chemicals	38 603	39 430
Gypsum products	8 850	2 314
Concrete products	63 254	211 608
Fertilizer, stock poultry feed	4 172	3 982
Other[2]	160 030	223 975
Total	4 512 637[r]	3 983 751

[1] Producers' shipments of quartz and silica for flux purposes.
[2] Includes asbestos products, ceramic products, frits and enamels, paper & paper products, roofing & other minor uses.
[r] Revised.

Three large consuming industries can be identified: they are the ferrous metal industry using foundry sand, the glass manufacturing industry and the non-ferrous metal processing industry using smelter flux.

Silica producers in Canada are listed in Table 4 with name of companies and quarry locations.

TABLE 4 - Canadian Producers of Silica, 1983

PROVINCE - COMPANY	LOCATION
Newfoundland	
1. Erco Industries Ltd. (Dunville Mining Company)	Villa Marie
Nova Scotia	
2. Nova Scotia Sand & Gravel Ltd.	Shubenacadie
New Brunswick	
3. Chaleur Silica Ltd.	Bass River
Quebec	
4. Baskatong Quartz, Inc.	Charlevoix
5. Indusmin Ltd. (Quebec Silica Division)	St-Donat St-Canut
6. Sable de Silice Crémazie Inc.	Ormstown
7. Armand Sicotte & Sons Ltd.	Ste-Clotilde
Ontario	
8. Indusmin Ltd. (Ontario Silica Division)	Killarney
9. B-Mac Silicon Aggregates Ltd.	Bracebridge
Manitoba	
10. Steel Brothers Canada Ltd.	Black Island
Alberta	
11. Sil Silica Ltd.	Bruderheim

Source: Energy, Mines and Resources Canada

Market Outlook

There are indications that the Canadian Silica industry is awaiting the end of the current recessionary conditions to undergo a period of significant growth. Because metallurgical flux consumes almost half of the silica produced, a recovery in the base-metal industries would be necessary to boost silica tonnages significantly. Amounts of silica consumed in the manufacture of glass and glass fibre, as well as foundry sand can be expected to increase as the markets for these products improve.[3]

Top-quality, low-cost sand is readily available from suppliers in the U.S.A., therefore discouraging large-scale development of available Canadian silica sand sources. The U.S. deposits are very pure, requiring only simple, low-cost mining and processing. Combined with low freight rates, it is possible for U.S. suppliers to sell silica in Canada at a low price. Canadian producers are at a disadvantage because the nature of the deposits requires more intensive and higher cost processing, and transportation costs to markets are at a much higher rate per tonne per kilometer. However, some producers are competing effectively by increasing their tonnage of premium grade silica sand, thus increasing the quantity of high-purity domestic sand available to consumers. A continuation of this trend will significantly decrease imports of this commodity.[5]

In the long term, the fields of fibre optics, solar grade silicon and quartz culture are likely to become important consumers of silica. Significant improvements in mineral processing technology would be required for any of the current Canadian operations to achieve these stringent raw material specifications.[3,5]

Silica occurs in many forms, from unconsolidated sand and quartz to opal (an amorphous form). Deposits of industrial interest vary in purity, sometimes as much as 98% SiO_2, often much less. Common impurities include alumina, iron, calcite, magnesia, mica, and clay. The chemical composition of samples of Ontario silica are shown in Table 5.

TABLE 5 - Chemical Composition of Silica Samples[2]

COMPONENT	SAMPLE %		
	1	2	3
SiO_2	98.19	96.98	99.40
Al_2O_3	0.94	1.76	0.30
F_2O_3	0.36	0.75	0.13
FeO	-	-	0.13
MgO	0.06	0.05	-
CaO	0.03	0.03	-
TiO_2	0.05	0.09	-
Na_2O	0.07	0.04	-
K_2O	0.50	0.50	-

NOTE:
1. Killarney, Ont. - quartzite
2. Crosby, Ont. - quartzite
3. Kingston, Ont. - Potsdam Sandstone

Physical and chemical properties can often be modified to meet specific user specifications. Qualities of interest include: particle size, particle shape (determines abrasiveness), and the level of certain impurties. Silica melts at 1728°C and has the ability to sustain loads even when temperatures approach the melting point, making it an extremely useful refractory material.

Some physical properties are shown in Table 6.

TABLE 6 - Properties of SiO_2 (Quartz)[6]

Specific Gravity	2.65
Melting Point (°C)	1610
Solubility	Insoluble in H_2O, soluble in HF, slightly soluble in alkali
Refractive Index	1.55
Hardness (mohs scale)	7

Uses of silica include: the manufacture of ferrosilicon, silicon carbide, glass, sodium silicate and enamels; as foundry flux in acid process, as refractory brick, and industrial fillers.

In examining a deposit with a view to commercial utilization, specifications may require that the following features be investigated:[2]

1. Mineralogy; what percentage of silica; what accessory minerals.

2. Chemical purity, including analysis of silica, alumina, iron, lime, magnesia and alkalis.

3. Grain size: sizing and sorting of the grains checked by sieve analyses.

4. Roundness or angularity of the grains.

5. Toughness of the grains.

6. Cleanliness and percentage of fines present.

Specifications set by consumers depend on intended use. Table 7 shows criteria by use.

TABLE 7 - QUALITY CRITERIA FOR SILICA, BY USE[1]

FORM	USE	SPECIFICATIONS		
		Grain Size	% Impurities	Other
Lump Silica	Flux	8 - 25 mm	High silica content, iron and alumina not serious in small quantities	Should not decrepitate
	Silicon Alloys	25 - 150 mm	$SiO_2 > 98\%$; Fe_2O_3 & $Al_2O_3 < 1\%$ or $< 1.5\%$ combined. Lime and magnesia $< 0.2\%$, no phosphorous arsenic	
	Silica Brick	- 2.36 mm	$SiO_2 > 97\%$; Fe_2O_3 & $Al_2O_3 < 1\%$ or $< 1.5\%$ combined; low lime & magnesia	
	Aggregate Abrasive	Depends on use		Used in concrete and as grinding media
Silica Sand	Glass	100 - 600 µm	99.6% SiO_2; 0.03% Fe_2O_3; 0.15% Al_2O_3, low lime, magnesia & moisture	Uniformity & grain size important Angular grains preferred
	Silicon Carbide	+ 150 µm (the bulk +500 µm)	$SiO_2 > 99\%$; Fe_2O_3 & $Al_2O_3 < 0.1\%$ each. No lime, magnesia & phosphorous	
	Hydraulic Fracturing	500 - 850 µm	- No acid consuming constituents - High SiO_2	- Well rounded grains - Clean and dry - High compressive strength
	Foundry	70 - 850 µm	SiO_2 high; low aluminum, iron, sodium & potassium oxides	Well rounded grains in closely sized ranges
	Sodium Silicate & Other Chemicals	150 - 850 µm	$SiO_2 > 99\%$; $Al_2O_3 < 0.25\%$; lime and magnesia combined $< 0.05\%$; $Fe_2O < 0.03\%$	
	Other Uses	Coarsely ground Closely sized		Used as grit in sand blasting, sandpaper, water filtering media, cement manufacturing
Silica Flour	-Enamel frits -Filler in paints, rubber -Abrasive in Soaps and Cleansers	Fine Powder	$SiO_2 > 97.5\%$; $Al_2O_3 < 0.5\%$, $Fe_2O_3 < 0.2\%$	

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THE TALC INDUSTRY

ENERGY CONSERVATION IN THE INDUSTRIAL
MINERALS PROCESSING SECTOR - COMMINUTION

(Phase I - Plant Studies)

Work on this Project was conducted by
Canada Cement Lafarge Ltd.,
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APPENDIX - Industry Review

1. General Information
2. Product Characteristics
3. Quality Criteria

REFERENCES

1. INTRODUCTION

Cooperating Company:

Bakertalc Inc.

Plant Location:

Highwater, Quebec

The report introduces first the company that cooperated in the study. A description follows of the comminution processes monitored during the field work at the plant. The measurements made and results obtained are then reported and discussed and conclusions drawn.

For readers who are not familiar with the talc industry, an appendix entitled "Industry Review" is added. Details concerning data collection and field work, as well as other raw data or measurements, are available in working papers.

2. COMPANY DESCRIPTION

2.1 Products

Bakertalc Inc., a Canadian company formed in the late 1930's, operates a mine at South Bolton and a milling plant at Highwater with a head office in Montreal.

The plant has a capacity of about 10,000 tonnes per annum. Three major grades of talc are produced: ground products A1 and A3, and floated and pulverized product #903. Another ground product A2 is produced in small quantities.

Product A1 is 95% passing a 45 μm sieve while product A3 is 99.8% passing 45 μm. The talc content of these products is 65-70%.

Product #903, having passed through the flotation process, is 98% talc with an average particle size of about 1 μm. The loss on ignition (L.O.I.) is 5-6% while that of pure talc is 4.2%.

Marketing and distribution of Bakertalc products, shipped in 25 kg bags, are handled by St. Lawrence Chemicals of Montreal. The main geographical market areas are Quebec and Southern Ontario.

2.2 Raw Material

The talc ore is obtained from an underground mine located about 15 kilometers from the plant. The deposit is a mixture of hard and soft talc and soapstone. The mining operation is carried out at approximately 200 m below the surface, using the blast hole stoping method into a 75 m glory hole. Selective mining controls the composition of the rock. The ore is then moved to a 2.25 m^3 bucket in an

inclined shaft to the surface. The mined ore is stored in loading bins and trucked to the mill.

The talc ore varies in size distribution, chemical analysis, and moisture. The size distribution of the ore was observed to be a maximum size of about 25 cm slabs with 40% of the material passing 5 cm. Due to moisture content, some fine material in the ore adheres to the larger pieces and passes over the screen to the crusher.

The plant operators do not attempt to control the chemical composition of the ore as produced by selective mining but accept the material for processing as received.

3. PROCESS DESCRIPTION

3.1 General

The production line at the Bakertalc plant consists of a mixture of older, less sophisticated equipment as well as machines of very recent design involving some of the most modern processing techniques. The process can be subdivided into four stages; primary-secondary crushing and drying, the Raymond mill grinding circuit and associated equipment, the flotation process, and the Bauer Hurricane pulverizer circuit. The flotation and Bauer Hurricane circuits are closely linked since all the flotation product is processed through the pulverizers. Figure I shows a schematic arrangement of the Bakertalc process flow. Since all products are generally bagged as they are produced, the bagging department can be considered as part of the process department.

3.2 Crushing and Screening

Ore is held in a bin leading to a vibrating screen-feeder (Figure II) equipped with a single deck of 65 cm x 65 cm and 5 cm openings. It is driven by a 5 HP motor and the feed rate is controlled manually by on-off action. The screen oversize discharges to a jaw crusher of 60 cm x 30 cm opening and a discharge opening of about 5 cm. The crusher drive is 50 HP.

The vibrating screen undersize drops to a belt and is fed to a rotating dryer fueled by No. 2 furnace oil. The dryer is of approximately 1.25 m diameter by 4.5 m in length and is fitted with lifters to pick up the material and drop it through the airstream. Draft through the dryer is supplied by a 10 HP induced draft fan venting directly to atmosphere. Material passes through the dryer

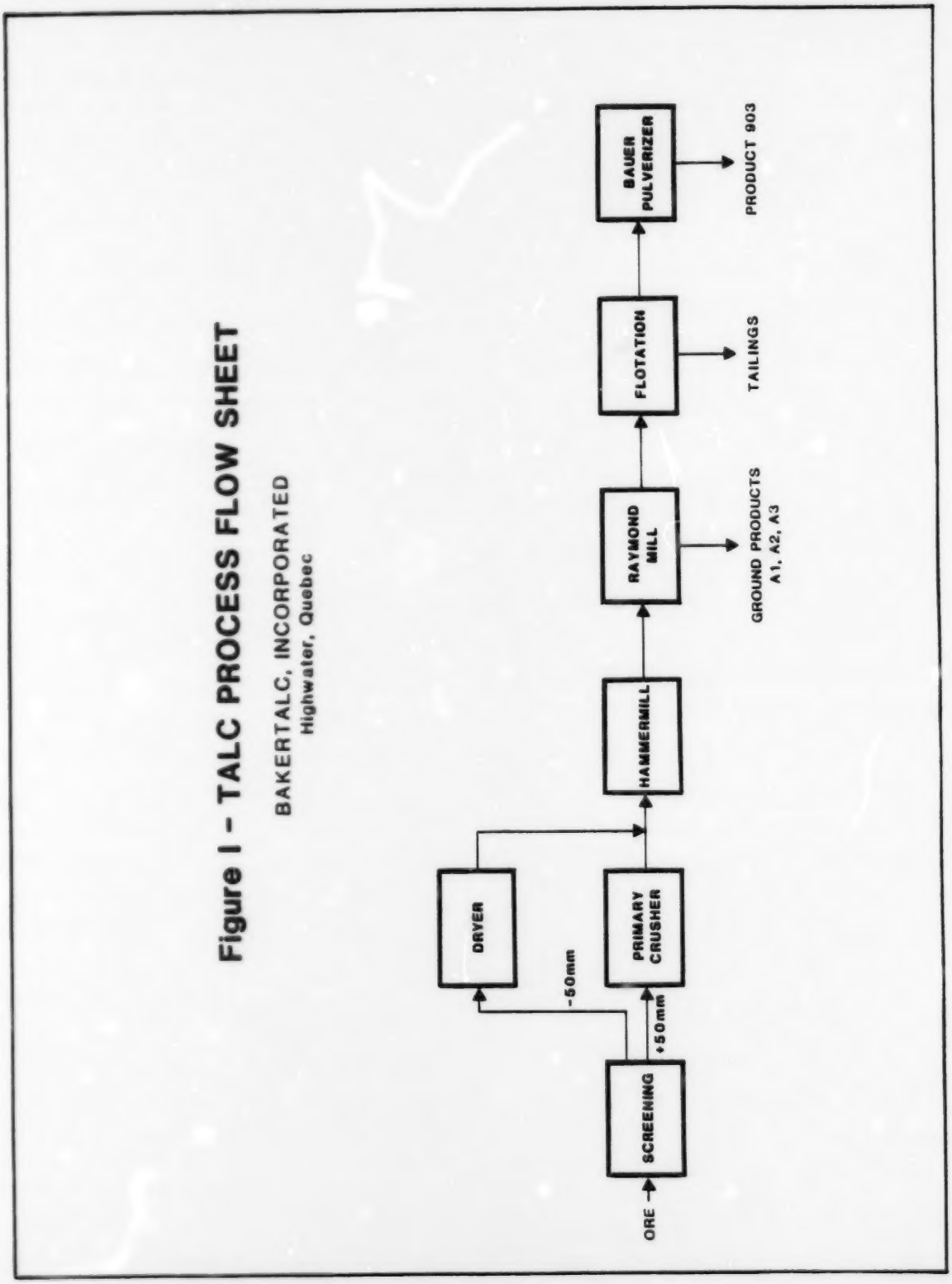
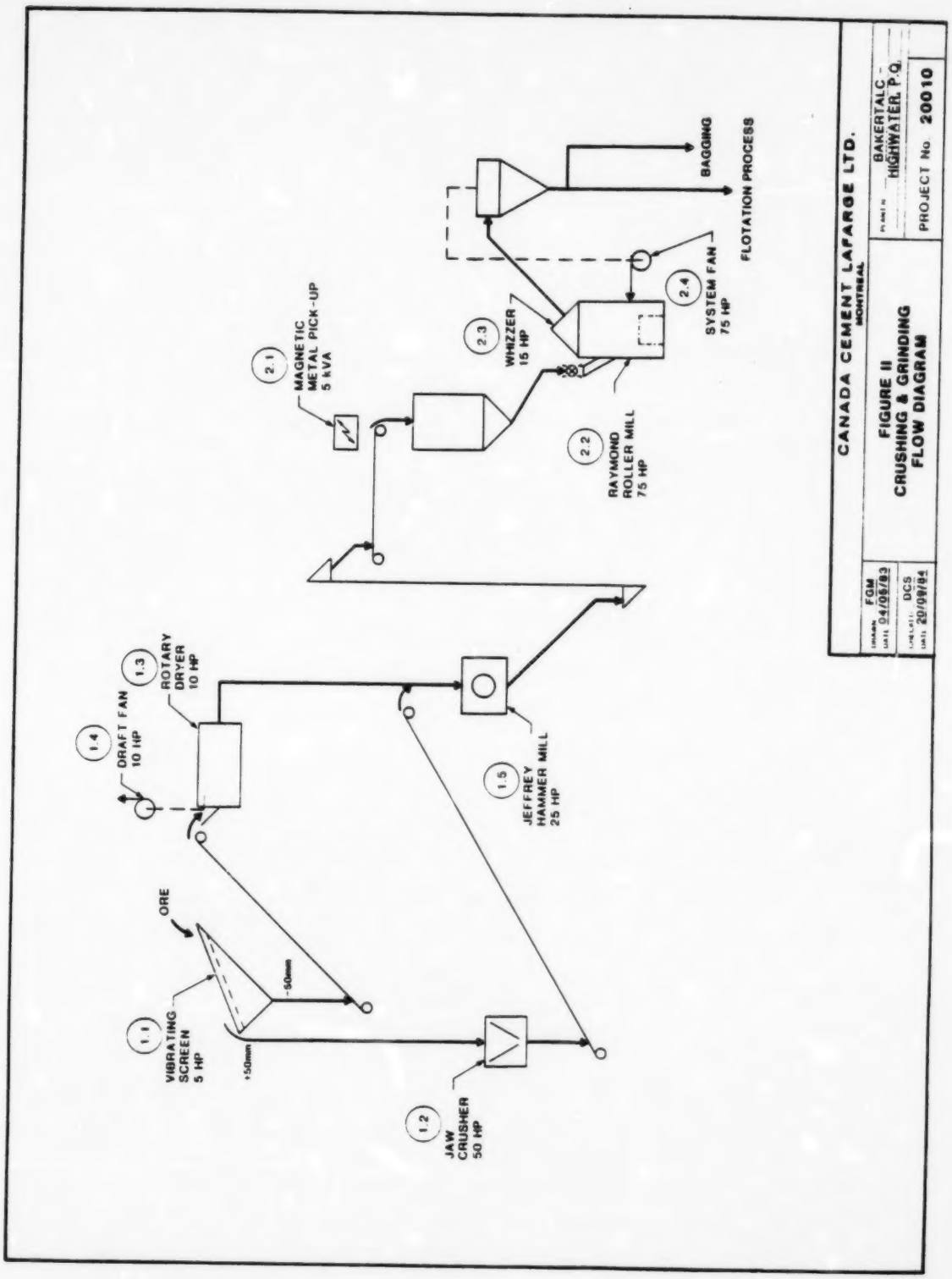


Figure I - TALC PROCESS FLOW SHEET
BAKERTALC, INCORPORATED
Highwater, Quebec
ORE
SCREENING
+50mm
-50mm
DRYER
PRIMARY CRUSHER
HAMMERMILL
RAYMOND MILL
GROUND PRODUCTS A1, A2, A3
FLOTATION
TAILINGS
BAUER PULVERIZER
PRODUCT 903


ORE
1.1 VIBRATING SCREEN 5 HP
-50mm
+50mm
1.2 JAW CRUSHER 50 HP
1.3 ROTARY DRYER 10 HP
1.4 DRAFT FAN 10 HP
1.5 JEFFREY HAMMER MILL 25 HP
2.1 MAGNETIC METAL PICK-UP 5 kVA
2.2 RAYMOND ROLLER MILL 75 HP
2.3 WHIZZER 15 HP
2.4 SYSTEM FAN 75 HP
BAGGING
FLOTATION PROCESS
CANADA CEMENT LAFARGE LTD.
MONTREAL
DRAWN FGM 94/06/03
CHECKED DCS 20/08/84
FIGURE II
CRUSHING & GRINDING
FLOW DIAGRAM
PLANT BAKERTALC - HIGHWATER, P.Q.
PROJECT No. 20010

counter current to hot combustion gases. The fuel rate is adjusted by a fuel valve and the overall fuel consumption is measured monthly by inventory checks. The drive is equipped with a 10 HP motor.

The dried material mixes with material from the jaw crusher and feeds directly to a 25 HP Jeffrey Mini-Mill.

The -2 cm material goes by elevator and belt conveyor to storage bins. The head pulley of the belt serves as a 5 kVA electro-magnet with adjustable current control to remove scrap metal. Crushed ore is reclaimed from the storage bins by elevator. A second belt conveyor delivers feed directly to the roller mill feed bin.

While the hammermill is the bottleneck in the crusher department, the system has sufficient capacity to operate only a few hours a day to supply the rest of the plant with feed.

3.3 Raymond Mill

The roller mill, in a sense, represents the core of the process, since all products made at Bakertalc pass through this mill at some stage in their processing. The mill is a Raymond "High-Side" model 5458 powered by a 75 HP motor. Grinding action takes place between rollers and a grinding table.

The Raymond mill has an internal classifier that recirculates particles not meeting fineness requirements to the grinding zone. The classifier, or whizzer, consists of a set of revolving blades, the speed of which determines the size of the particles allowed to pass through. The

whizzer is powered by a 15 HP drive which is independent of the mill drive. The motor is coupled to the whizzer through an infinitely variable speed ratio transmission.

Ground material is circulated in the mill and subsequently removed by an upward air sweep through the mill. This air sweep is provided by a 75 HP system fan located with its outlet near the bottom of the mill. Air is forced into the bottom of the mill and upward through a duct carrying with it particles of finished product. The air passes through a cyclone where the entrained material is removed and then returns to the inlet of the system fan for recirculation to the mill. The air sweep is essentially closed circuit. The material removed from the airstream by the cyclone then passes to the bagging bin or flotation feed bin depending on the product being made.

The Raymond mill is fed by gravity through a rotary feeder. The feed rate and, consequently, the load in the mill, is controlled by on-off action of the rotary feeder. The controlled variable is the differential pressure across the mill, which is proportional to mill load. Air taps at the bottom and top of the mill provide differential pressure measurements to a switch operating at a set-point. Despite the non-continuous nature of the control, the mill loading is kept relatively constant.

3.4 Flotation

The flotation circuit separates the talc in the ore from the impurities. A frothing agent is added to a mixture of ground talc ore and water. Particles of talc adhere to froth bubbles in the liquid and float to the surface where the froth and talc are skimmed off.

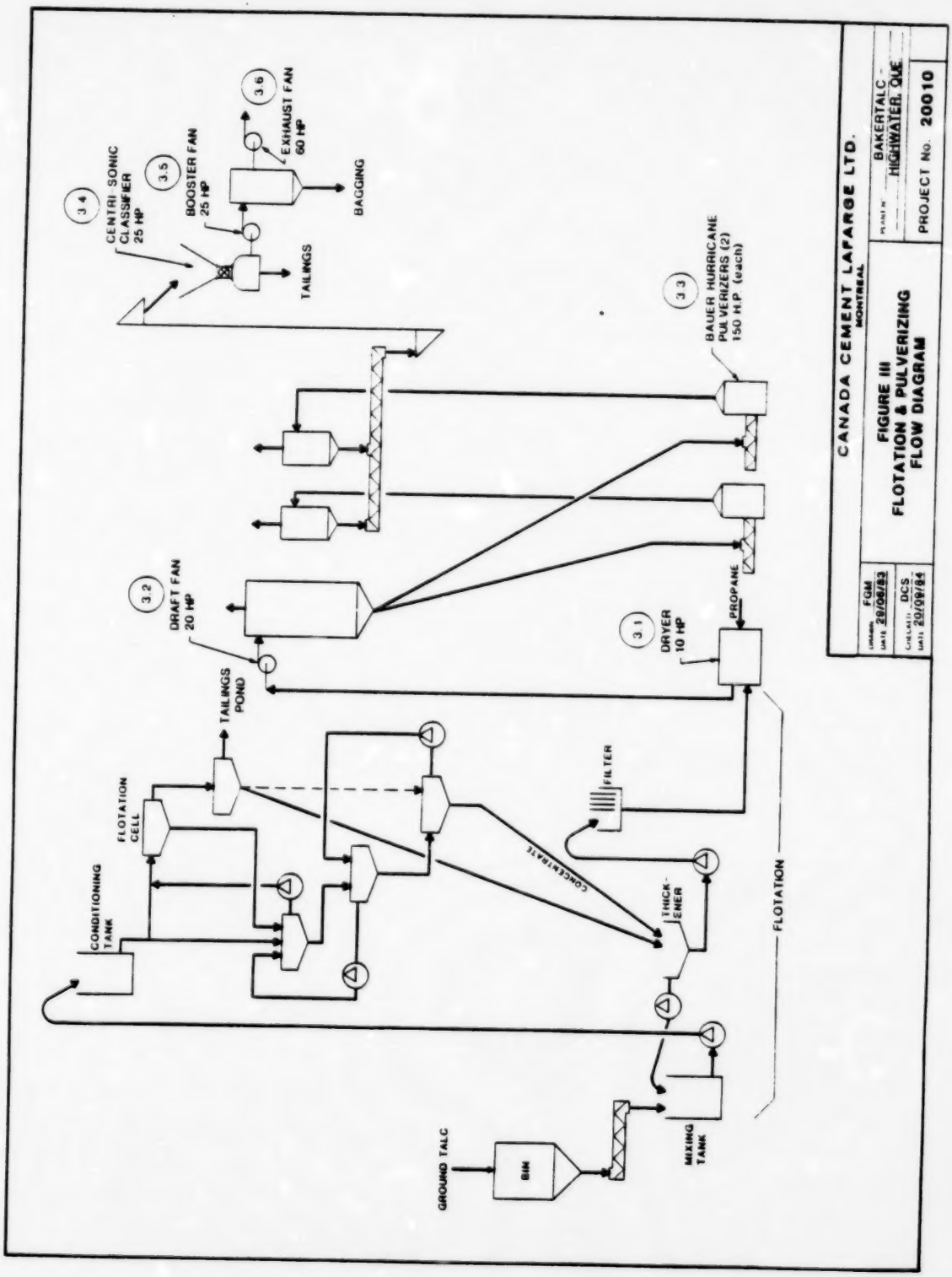
The flotation circuit (Figure III) consists of a mixing tank, conditioning tank, five float cells, thickener and filter. The five float cells are made up of two roughers, two cleaners and a scavenger.

At the Bakertalc plant, the flotation process begins with the talc being fed into the mixing tank by screw conveyor. The tank is kept filled with talc-water slurry, is equipped with a high speed stirrer and provided with a constant flow of water. The slurry is then pumped to the conditioner, another large tank equipped with a stirrer where further mixing takes place and a small quantity of frothing agent is metered in by a pump.

The slurry then passes to the roughers. The concentrate flows to rougher #2, then to the first and second cleaner in sequence. The second cleaner provides concentrate for the thickener. The tailings flow through the circuit is counter current to the floated product.

The thickener densifies the slurry and feeds the filter where moisture content is further reduced. Water from the thickener and filter are returned to the mixing tank at the beginning of the flotation process.

The filter cake passes to a propane fired rotary dryer and flows counter-current to the gas stream. The material is removed from the dryer by entrainment in the gas stream and goes through a fan to a bin-baghouse where it is collected and stored as feed to the Bauer Hurricane mill circuit. A clean burning fuel like propane is required by the dryer to prevent darkening of the floated product by combustion products.


CANADA CEMENT LAFARGE LTD.
MONTREAL
FIGURE III
FLOTATION & PULVERIZING
FLOW DIAGRAM
BAKERTALC - HIGHWATER, QUE
PROJECT No. 20010
FGM 28/06/83
DCS 29/09/84
GROUND TALC
BIN
MIXING TANK
CONDITIONING TANK
FLOTATION CELL
TAILINGS POND
DRAFT FAN 20 HP
3.2
DRYER 10 HP
3.1
PROPANE
BAUER HURRICANE PULVERIZERS (2) 150 H.P. (each)
3.3
CENTRI SONIC CLASSIFIER 25 HP
3.4
BOOSTER FAN 25 HP
3.5
EXHAUST FAN 60 HP
3.6
TAILINGS
BAGGING
FILTER
CONCENTRATE
THICKENER
FLOTATION

3.5 Pulverizer Circuit

The purpose of the Bauer Hurricane mill circuit is to reduce the particle size of the talc from the flotation circuit to the order of 1 μm.

The Bauer Hurricane circuit (Figure III) at Bakertalc is comprised of two 150 HP pulverizer-classifiers operating in parallel, two baghouse collectors, screw conveyor-elevator arrangement to convey material from the baghouses to the single Centri-Sonic classifier, product booster fan at the outlet of the classifier, product baghouse collector and fan. The material for the pulverizer circuit is fed from the holding bin directly to the mills via individual, variable speed screw feeders controlled by mill power demand. The feed enters near the bottom of the mill and passes upward through the grinding zone, made up of blades revolving at high circumferential speed. Grinding action takes place by vortex formation between blades causing inter-particle collisions. This principle is required since the particles are too small to be broken by shock and impact.

The material passes upward through an internal classifier, which consists of a set of blades attached to the same drive shaft as the grinding blades, separating out oversize particles for return to the grinding zone. Air flow is controlled by louvers and is provided by a fan in the top of the pulverizer. Classified material is entrained in the airstream and passes to the individual baghouses. The material then goes to a small bin and is fed at a fixed rate by rotary valve into the top of the classifier. A dispersing rotor disagglomerates feed particles and they pass through the classifier assembly. Classification occurs by the action of the external booster fan

which pulls sufficiently fine particles through the rotating assembly. Oversize particles are rejected by centrifugal action and are treated as tailings. "Cut point", the size at which a particle is accepted or rejected, is controlled by speed of the classifier assembly, air flow rate and feed rate. The classifier is driven by a 25 HP motor.

The finished product passes through the 25 HP product booster fan and transport duct to a baghouse that collects the material and feeds it to the bagging machine. The baghouse is exhausted by a 60 HP fan. Table 1 summarizes the equipment in the Bakertalc process.

TABLE 1 - Equipment List

EQUIPMENT		MOTOR*	
No.	TYPE/MAKE/MODEL	HP	AMPS
1.1	Vibrating Screen - 2 in. sq. opening	5	5.5
1.2	Jaw Crusher - 24" x 12"	50	50
1.3	Rotary Dryer (No. 2 Oil)	10	10
1.4	Draft Fan	10	10
1.5	Jeffrey Hammermill (20 x 12)	25	25
2.1	Magnetic Metal Pick-up (5 KVA)	-	10
2.2	Raymond Roller Mill 5458	75	75
2.3	Whizzer	15	15
2.4	System Fan	75	65
3.1	Dryer (Propane)	10	10
3.2	Draft Fan	20	20
3.3	Bauer Hurricane Pulverizer (2) Type 730	150	150
3.4	Centri-Sonic Classifier No. 753	25	25
3.5	Product Booster Fan	25	25
3.6	Dust Collector Fan	60	60

* All Motors are 550 Volts.

4. RESULTS AND DISCUSSION

4.1 Talc Ore Crushing and Grinding

4.11 Electrical Measurements

Measurements in the crushing circuit were made on the crusher and hammermill, rotary dryer drive and induced draft fan. Motors whose consumption tended to vary in response to varying loads were measured with the wattmeter recorder and the consumption characteristics determined directly from the graph. The crusher and hammermill were measured in this manner. For motors with relatively consistent loads, this power consumption was measured by taking amperage measurements and converting to kilowatts.

The Raymond mill circuit involves three motors: the mill motor, the classifier or "whizzer", and the system fan. Since all three components of the system are related to each other with regard to load, each motor was measured with the wattmeter. These measurements were taken while the mill was producing A1 and were repeated for production of flotation feed. While the whizzer and system fan showed fairly constant power consumption rates, some slight fluctuation was observed for the mill motor. This was due to the on-off action of the rotary feeder with the result that the mill load varied slightly around the median point.

Since the Raymond mill system was measured with the wattmeter, all consumptions were reported as maxima, minima and average. Results for the crushing and grinding systems are reported in Table 2.

TABLE 2 - Talc Ore Crushing and Grinding

No.	EQUIPMENT	MOTOR HP	POWER OBSERVATIONS - kW		
			MAX.	MIN	AVG.
1.1	SCREEN	5			
1.2	CRUSHER	50	11	8	10
1.3	DRYER	10	3	3	3
1.4	I.D. FAN	10	3	3	3
1.5	HAMMERMILL	25	11	4	7
2.1	MAGNET	5 kVA			
2.2	RAYMOND MILL	75			
	PRODUCT A1		29	26	28
	FLOTATION FEED		23	21	22
2.3	WHIZZER	15			
	PRODUCT A1		8	8	8
	FLOTATION FEED		3	2	3
2.4	SYSTEM FAN	75			
	PRODUCT A1		57	56	57
	FLOTATION FEED		52	51	51

4.12 Flowrates

The manner in which the crushing system was operated caused some difficulty in estimating the overall throughput of the system as well as individual stream flowrates. The system was observed in operation and then the decision made to stop the belts while carrying typical loads. A known length of material was removed from each belt. The weight of sample, combined with the measured linear belt speed gave a calculated flowrate. Flowrates for various crushing circuit streams are presented in Table 3.

TABLE 3 - Flowrate Data for Crushing Circuit

Stream	Belt Length Sampled (m)	Sample Weight (kg)	Belt Speed (m/min)	Calculated Flowrate (t/h)
Crusher Product	1.2	37.6	11.4	21.4
Screen Undersize	1.2	28.3	81.9	115.9
Circuit Product	0.94	19.7	18.8	23.6

The flowrate for screen undersize is unrealistically high since, overall, the production rate of the crushing circuit must be roughly the sum of screen undersize and crusher product. This problem is linked to the intermittent nature of the operation. The belt carrying screen undersize has a widely varying load, and, during testing, was stopped at maximum load. While a high flowrate of undersize was indicated, it is estimated that the belt carries this degree of load less than 10% of the time. A more reliable measure of overall production rate was obtained from the product belt, which carried a reasonably steady load.

Although the Raymond mill consists of a grinding zone and a separate classifier unit, it was not possible to treat the mill as closed circuit. The only flowrate which could be estimated for the Raymond mill system was the overall throughput or production rate. This required observation of bagging rate for product A1. Production rate figures for product A3 and flotation feed were obtained from plant records (Table 4).

TABLE 4 - Production Rates for Raymond Mill

PRODUCT	PRODUCTION RATE (t/h)
Flotation Feed	5.0
Product A1	2.3
Product A3	1.0

4.13 Size Distribution

Size distribution determinations were not carried out on screen feed and crusher feed due to the size of sample required to make the test statistically accurate. Therefore, these streams were characterized by observation during actual operation of the crushing system. The results of these observations are as follows:

Stream	Observed Particle Size Distribution
Screen Feed	Maximum Size : 30 cm x 20 cm Average Size : 15 cm - 20 cm Fraction minus 5 cm : 40%
Crusher Feed	Maximum Size : 30 cm x 20 cm Mainly : 15 cm - 20 cm Minimum Size : 5 cm

Samples of screen undersize, crusher product and crushing circuit product were tested for particle size distribution at the Belleville Research Lab of Canada Cement Lafarge Ltd. The results are presented in Table 5.

TABLE 5 - Crushing Circuit Particle Size Distributions

Size	% Passing		
	Crusher Product	Screen Undersize	Circuit Product
63 mm	94.2	100.0	100.0
31.5	29.3	66.5	96.1
25	26.0	61.9	88.8
19	19.7	53.8	75.3
12.5	14.5	44.6	60.7
9.5	11.8	39.1	49.9
4.75	7.9	28.3	32.5
2.36	5.4	20.3	21.8
1.18	3.9	14.2	15.3
600 μm	2.6	8.8	10.7
300	1.9	5.6	7.9
150	1.3	3.5	5.7

The results show that most of the crusher product is between 31.5 mm and 63 mm. Some fine material below 1 mm is also observed in the crusher product. This may result from the crushing itself and from adherence of small particles to the larger ones because of moisture in the ore. These particles are thus carried over the screen to the crusher and are present in crusher product. Analysis of results for screen undersize shows all material smaller than 63 mm with a somewhat larger proportion of -1 mm material as compared to crusher product.

This sample represents the fine fraction of the ore. An important note regarding crushing circuit product is that, while it is intended that all product be minus 19 mm, the results show that, in fact, only 75% of the product meets this requirement. However, it was suggested that some relatively coarse material actually enhances the performance of the Raymond mill.

Particle size distribution testing on the Raymond mill system was done on the flotation feed and products A1 and A3. The results were generated by sedigraph at the Belleville lab and are presented in Table 6. The results show that, with regard to percent passing 45 μm, the finished products from the Raymond mill are essentially meeting specifications. The flotation feed is slightly below the target of 80% passing 45 μm (75% passes according to the sedigraph results).

TABLE 6 - Raymond Mill Particle Size Distribution

Size (μm)	% Passing		
	Flotation Feed	A1	A3
100	98.5	99.0	99.5
70	93.0	97.0	99.0
50	79.5	93.5	99.0
40	70.5	87.0	97.5
30	57.5	74.0	95.0
25	52.0	66.0	91.0
20	43.0	54.5	82.0
15	33.0	42.0	64.0
10	20.0	25.5	35.5
8	15.0	19.5	24.5
6	10.5	13.5	16.5
4	6.5	8.5	10.5
2	2.0	3.0	4.0

4.14 Grindability

On the sample of crushing circuit product, the grindability tests on the Bakertalc ore gave a Bond Work Index and Hardgrove Grindability Index of 8.345 kWh/Ton and 93, respectively. These results typify a material which is relatively easy to grind.

4.15 Specific Energy Consumption

The consumption of electrical energy at Bakertalc expressed as kilowatt-hours per tonne can be calculated for a final product or intermediate material. The specific consumption for the crushing circuit (Table 7) is 0.95 kWh/t. Specific energy consumption for the Raymond mill (Table 8) is significantly higher than for crushing since the fineness of the products is much greater. The percentage of specific energy used for grinding in the Raymond mill remains very nearly the same from product A1 to flotation feed, although the two products are quite different in fineness.

TABLE 7 - Crushing Power Consumption

	kWh/tonne	%
Crushing Only	0.72	76
Auxiliaries	0.23	24
Total	0.95	100

TABLE 8 - Grinding Power Consumption

	kWh/tonne	
	Specific	%
Grinding Only		
Product A1	12.0	30.0
Flotation Feed	4.4	29.1
Auxiliaries		
Product A1	28.0	70.0
Flotation Feed	10.7	70.9
Total Consumption		
Product A1	40.0	100
Flotation Feed	15.1	100

4.2 Flotation and Pulverization

4.21 Electrical Measurements

Electrical energy consumption in the flotation circuit arises mainly from the use of stirrers in the flotation cells and pumps to move the talc-water slurry between the various tanks and cells. Since no comminution takes place, no attempt was made to estimate power consumption.

In the pulverization department, the two hurricane mills and the Centri-Sonic classifier were studied using the wattmeter recorder. The remaining consumers of electrical energy were mainly fans with relatively constant loads. These were measured by amps and the kilowatt demand calculated. The results are presented in Table 9.

TABLE 9 - Purified Talc Pulverizing

No.	EQUIPMENT	MOTOR HP	POWER OBSERVATIONS - kW		
			MAX.	MIN	AVG.
3.1	DRYER	10	3	3	3
3.2	DRAFT FAN	20	11	11	11
3.3	PULVERIZER B1	150	70	65	68
	B2	150	78	73	76
3.4	CLASSIFIER	25	7	5	6
3.5	BOOSTER FAN	25	10	10	10
3.6	EXHAUST FAN	60	22	22	22

4.22 Flowrates

The Bauer mills, like the Raymond mill, consist of a grinding zone and classifying zone in one process unit. The Centri-Sonic classifier, located externally to the mills, normally produces only a small amount of rejects. Therefore, the pulverizing system was treated as open

circuit. The flowrate of Product 903 was taken from plant records and, including both mills, was 0.9 t/h.

The production rate of talc from the flotation circuit was not specifically measured but it is known that the yield of the circuit is 50%, i.e., two tonnes of material from the Raymond mill are required to produce one tonne of floated product.

4.23 Size Distribution

Size distribution determination by sedigraph for the flotation and pulverizing circuits was carried out on the dried flotation product and the finished Product 903. The results are presented in Table 10. A comparison of the results of the flotation product with flotation feed reveals a greater proportion of smaller particles in the floated product. This may result from finer grinding of talc particles in the Raymond mill as compared to particles of impurities.

TABLE 10 - Pulverizing Particle Size Distribution

Size (μm)	% Passing		
	Feed	Flotation Product	Product 903
100	98.5	100.0	
70	93.0	97.5	100.0
50	79.5	88.0	99.5
40	70.5	79.0	99.5
30	57.5	67.5	99.0
25	52.0	61.0	99.0
20	43.0	51.0	99.0
15	33.0	40.0	98.0
10	20.0	23.0	94.0
8	15.0	16.5	89.0
6	10.5	10.5	69.0
4	6.5	6.0	14.5
2	2.0	1.5	5.0

The results of the sedigraph on the finished product demonstrate the extreme fineness to which the talc is eventually ground. The narrow range of size distribution is also evident by the steepness of the graph, Figure IV.

4.24 Specific Energy Consumption

Energy consumption is reported for pulverization only. This data is contained in Table 11.

TABLE 11 - Pulverizing Power Consumption

	kWh/tonne	
	Specific	%
Grinding Only	158.9	73.6
Auxiliaries	57.1	26.4
Total	216.0	100.0

This data reveals the very high energy consumption required to make the product 903 compared to the dry-milled products.

4.25 Comminution Power Consumption by Product

The comminution power requirements per tonne of product are summarized in Table 12.

TABLE 12 - Power Consumption

Department	Product A1		Product 903	
	kWh/t	%	kWh/t	%
Crushing	1	2.4	2	0.8
Grinding				
Raymond Mill	40	97.6	30	12.1
Pulverizer	0		216	87.1
Total	41.0	100.0	248	100
Flowrate (t/h)	2.3		0.9	

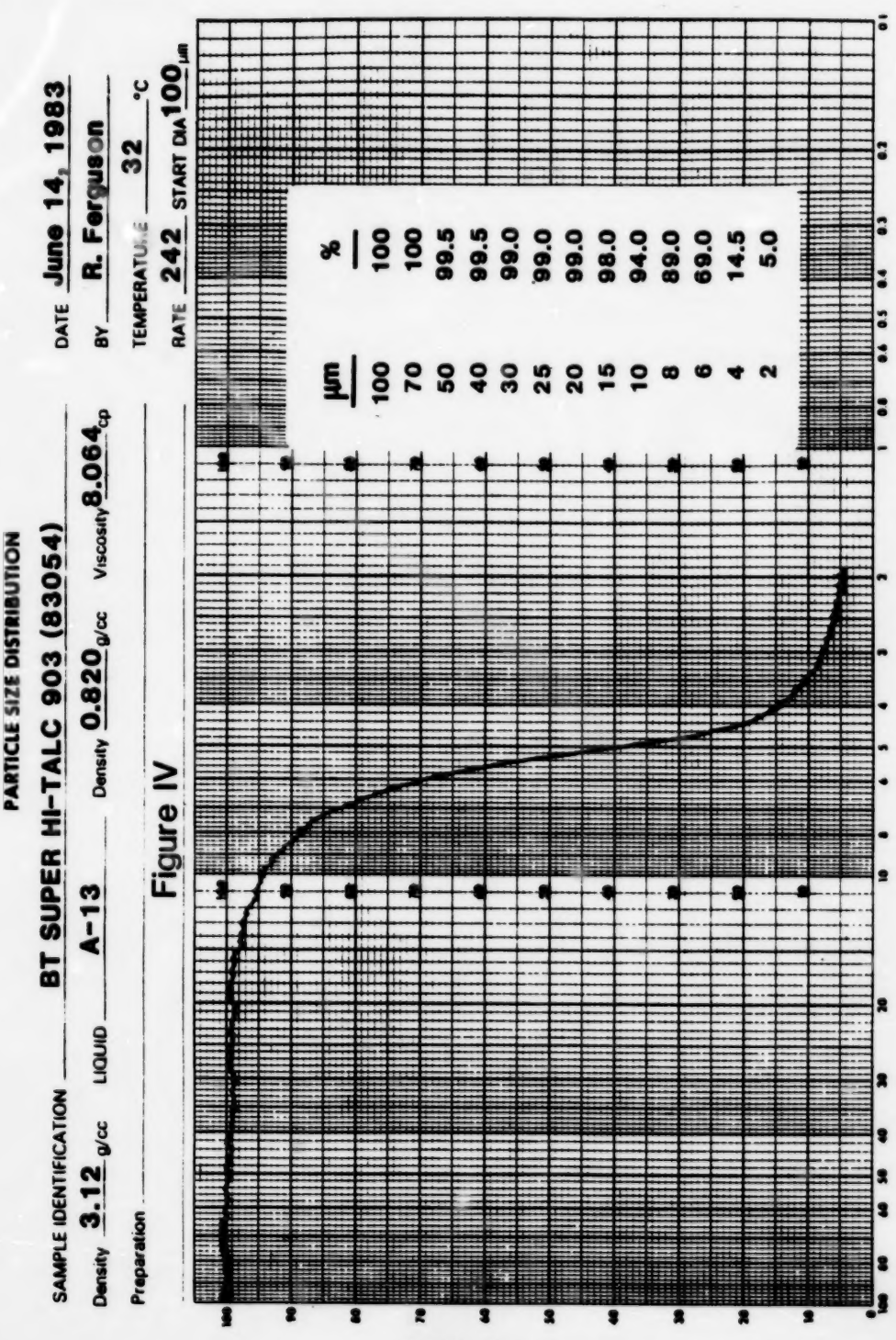

PARTICLE SIZE DISTRIBUTION
SAMPLE IDENTIFICATION BT SUPER HI-TALC 903 (83054)
Density 3.12 g/cc LIQUID A-13 Density 0.820 g/cc Viscosity 8.064 cp
Preparation
DATE June 14, 1983
BY R. Ferguson
TEMPERATURE 32 °C
RATE 242 START DIA 100 µm
µm %
100 100
70 100
50 99.5
40 99.5
30 99.0
25 99.0
20 99.0
15 98.0
10 94.0
8 89.0
6 69.0
4 14.5
2 5.0
CUMULATIVE MASS PERCENT
EQUIVALENT SPHERICAL DIAMETER, µm
micromeritics instrument corporation

Figure IV

Power demand for product 903 is six times greater than that of product A1, mainly due to the pulverizer which is required to give 903 a suitable degree of fineness.

It should be noted that the crushing power for 903 is double that of A1 because fifty percent of the crushed material is lost to benefication during production of 903.

4.26 Chemical Composition and Brightness

The most noticeable changes are in the silica content, which has gone from 37% to 57% (63% is the SiO_2 portion of pure talc) and the loss on ignition which has dropped from 20% to 8%.

TABLE 13 - Chemical Composition

	Flotation Feed %	Flotation Product %
SiO_2	37.24	56.86
$Al_2O_3 + TiO_2 + P_2O_5$	2.94	1.53
Fe_2O_3	6.48	3.89
CaO	2.22	0.29
MgO	29.83	29.54
Na_2O	0.00	0.00
K_2O	0.03	0.00
SO_3	0.31	0.09
L.O.I. (1050°C)	20.45	7.83

Brightness testing was done on the flotation feed and product as well as the three finished products. The results indicate that both fineness and purity of the talc play a role in brightness and both factors are strongly present in product 903 to give this material its desired characteristics. The progressive increase in material brightness can be seen as the talc passes through the process and becomes increasingly refined.

The ranking, in order of increasing brightness, is: flotation feed, A1, flotation product, A_3, and 903.

5. CONCLUSIONS AND RECOMMENDATIONS

The results generated by this study provide a good "snap-shot" at electrical energy consumption by Bakertalc Inc. in the area of crushing and grinding. The progression of consumption can be seen as the refinement of the talc proceeds through the stages of production. Relatively little energy is consumed in the screening and crushing with higher consumption for the various dry-milled products. Product 903 is by far the highest per tonne consumer of power because of additional processing and fineness of that particular product.

An important point noted with regard to the crushing circuit was that, while it is intended that the circuit product be minus 19 mm, sieve analysis of this sample showed that only 75% of the material met the requirement. Thus, more grinding work was passed on to the Raymond mill. Plant operators indicated, however, that some coarse material may improve mill operation since fine, relatively soft talc particles tend to coat grinding surfaces.

Raymond mill products were observed to be on target with regard to 45 μm fineness. The wear rate on this mill is evidently low since servicing or replacement of grinding surfaces has been minimal over the life of the mill. This is accounted for by the relative softness of the ore.

It is expected that iron content should decrease significantly through flotation since the ferruginous magnesite impurity has been removed. However, the reported Fe_2O_3 content of 3.89 seems relatively high. This suggests flotation efficiency may be improved by process tuning adjustments. Improved efficiency of the flotation circuit would decrease the impurities remaining in the floated

product which would in turn contribute to increased brightness of the final product 903. Flotation productivity could also be increased.

Power measurements indicate that the Bauer mill motors were operating at a power level somewhat below their ratings. While a 150 HP motor would be expected to draw near 100 kilowatts of power, the motors were measured at about 70 kilowatts. The cause of this was not clearly diagnosed during the study.

Despite these few areas where the comminution circuit may have been operating below full efficiency, the comminution data collected at Bakertalc is probably representative of the industry.

In perspective, based on information from this study and plant operating records, the proportion of total manufacturing cost attributable to electric energy consumption by comminution and auxiliaries is not large. While this consumption is nearly half the electrical consumption, electrical costs represent only about 10% of manufacturing cost. Thus, the effect on manufacturing cost of improvements to comminution processes would be small.

APPENDIX

INDUSTRY REVIEW

GENERAL INFORMATION

In Canada, talc is mined in Quebec and Ontario. Areas of production in the United States are Vermont, New York, Texas, Montana and California.

North American output is summarized in Table 1.

TABLE 1 - Talc & Pyrophyllite: North American Production[6]

COUNTRY	(000' tonnes)					
	1977	1978	1979	1980P	1981e	1982e
Canada	72	62	90	92	83	72
United States	1,093	1,255	1,318	1,125	1,218	1,030
Mexico	-	3	3	2	3	-

P - Preliminary e - Estimated
Sources: Minerals Yearbook Centennial Edition 1981
Mineral Commodity Summaries, 1982; EMR Canada

Talc, as a pure mineral, has a composition of 63.36% SiO_2, 31.89% MgO and 4.75% H_2O.[5] In practice, commercial talc rarely approaches this purity.

It is common to group talc, soapstone and pyrophyllite together. The chemical nomenclature and formulae for talc and pyrophyllite are:

Talc:	Hydrous magnesium silicate $Mg_6 [Si_8O_{20}] (OH)_x$
Pyrophyllite:	Hydrous aluminum silicate $Al_4 [Si_8O_{20}] (OH)_x$

Soapstone is used mainly in carving art and pyrophyllite for uses similar to talc.

Talc was formed by metamorphic or hydrothermal alteration of rocks rich in magnesia, mostly ultrabasic igneous rocks and sedimentary dolomite. Pyrophyllite was formed by hydrothermal alteration of acid igneous rocks.

Talc ores are generally beneficiated with relative ease and the by-products of a talc processing plant often have commercial value. Despite the relatively low purity of most ores, talc has a steadily increasing number of uses in cosmetics, ceramics, paper, plastics and rubber. It is subject to increasing demand for high purity and quality control. For example, until 1960, talc and talcose products were accepted by the cosmetics industry, based on rather loose and uncomplicated specifications. Cosmetic talc had to be reasonably light colored, have good "slip, be free of "gritty" or hard mineral particles and meet a certain fragance retention standard. The cosmetic industry has now set higher standards and new rulings from Federal agencies have made heavy demands on talc product quality. Typical talc quality criteria for specific uses are shown in Table 2.

TABLE 2 - Talc Characteristics for Specific Uses[5]

USE	CHARACTERISTIC
Paint	Colour (whiteness) Particle shape Packing quality Oil absorption Fine particle size Opacity
Paper	Free of grit Colour Opacity Particle size Low alkali content
Ceramics	Uniform chemical composition Constant shrinkage on firing Fired colour Particle size distribution

Talc mining operations are generally on a small scale of less than 270 tonnes per day with equipment that is usually unsophisticated and capable of producing only a few tonnes per hour. Talc mining needs good housekeeping because of purity requirements. Underground crushing may be done before the ore is transferred to the grinding plant.

Talc milling has traditionally involved dry-processing operations, although it is evolving from simple grinding plants to sophisticated processing operations. Talc processing plants now include flotation, sedimentation, hydrocycloning, dry and wet magnetic centrifugal sizing, spray drying and new grinding techniques. Talc is commonly ground using ceramic grinding media. Some specialized grinding equipment is required for processing talc for specific markets. Talc sold as paper filler generally meets an average particle size of less than 5 µm and may sometimes be less than 1 µm. This requirement is met with vertical shaft pulverizing mills and jet-milling equipment.

In large talc plants (+100,000 tpy), sophisticated laboratory procedures have been introduced to control product quality. Some plants have facilities for chemical and instrumental analysis, surface area determination, color, oil absorption, particle size and shape determination, packing quality and others.

Canadian Industry

The earliest recorded activity involving talc, soapstone and pyrophyllite in Canada was in the 1870's with a shipment of soapstone from a deposit in Quebec.[1] In 1896, a deposit in the Madoc district of Ontario was opened and mined intermittently over the next few years. Deposits in southern British Columbia and southwestern Alberta were discovered prior to 1920 and produced small amounts.

Current Canadian talc, soapstone and pyrophyllite production, with a breakdown of production value by province and imports are shown in Table 3.

At present, talc is mined by four companies in Canada, two in Quebec and two in Ontario.

Bakertalc Inc. produces talc from an underground mine in Quebec, southeast of Montreal. Ore from the mine is processed at the company's mill facilities at Highwater. Ore hoisting at the mine is by way of a 45° inclined shaft. High quality talc for use in the paper industry is produced by a modified flotation process. Some product has been used as a filler in plastics and paints. The company also produces a lower grade talc in a dry-milling process.

Capacity: 3,000 tpa dry-milled and 5,000 tpa flotation product.

B.S.Q. Talc Inc. (formerly Broughton Soapstone and Quarry) quarries talc from deposits in the Eastern Townships in Quebec, where several low-priced grades of ground talc are produced. Most is used in roofing materials or as a rubber filler.[3]

Capacity: 22,000 tpa.

Canada Talc Industries Limited produces talc from an underground mine at Madoc, Ontario.[1] A high quality product is produced for use as a filler in paint and plastics and for use in pharmaceuticals, cosmetics and lens polishing. The company is adding some micrometer grades and a 200 mesh ceramic grade to its product line. The mill circuit contains a jaw crusher, Raymond mills, pebble mills and classifiers.

Capacity: 25,000 tpa.

Steetley Mineral Group, through a subsidiary Steetley Talc Limited, produces talc from a deposit at Penhorwood Township in Ontario. The talc is a high purity, platey material and is produced by flotation.[3] Although the biggest market is as a pitch control agent in pulp, other uses include fillers in paint and plastics as well as cosmetics. Steetley anticipates that the market in plastics, especially in heat resistant polypropylene, could be good in the future.

Capacity: 25,000 tpa.

TABLE 3 - TALC, SOAPSTONE AND PYROPHYLLITE PRODUCTION, 1978-82[1]
(in thousands of tonnes and dollars)

PRODUCTION (Shipments)	1978		1979		1980		1981		1982P	
	t	$	t	$	t	$	t	$	t	$
Talc and Soapstone										
Quebec*	-	1,072	-	1,500	-	1,400	-	1,356	-	1,475
Ontario**	-	440	-	914	-	1,437	-	2,102	-	3,429
Total	-	1,513	-	2,414	-	2,837	-	3,458	-	4,904
Pyrophyllite										
Newfoundland	-	664	-	1,025	-	1,040	-	1,003	-	552
Total Production	62	2,177	90	3,439	92	3,877	83	4,462	72	5,456
Total Imports	33		50		50		30		35	

Sources: Statistics Canada; Energy, Mines and Resources Canada.
* Ground talc, soapstone, blocks and crayons
** Ground Talc
P Preliminary
- Not Available

Market Outlook

Except for minor shipments to South Africa, talc exports are to the United States where there is a rapidly growing demand for good quality filler for automobile plastics.[1] Most talc imports are from the United States and are high quality, high value materials for use in the paint, ceramic, paper and cosmetic industries. It is expected that high quality talc imports will be replaced somewhat in other industries by domestic products, as capacity for producing higher grades increases.

It is anticipated that the talc market in the paper industry will grow both in pitch control and in filler and coating applications. In the cosmetic market, competition may be keen in a few years as more companies vie for position. Another factor that is threatening in the cosmetic market is that corn starch can replace talc in applications like baby powder.[3]

Minerals competing with talc are feldspar, wollastonite and nepheline syenite in ceramics, mica in the roofing market, and specially purified, calcined and compounded clays in paint, paper and plastics. Titanium dioxide is not as competitive as a filler due to high cost. The most important competitors in the filler market are limestone and dolomite fillers. Limestone is considered to be the most versatile mineral filler and its widespread availability and, therefore, low transportation costs will ensure it continues to be competitive. As talc products increase in purity and quality, more talc by-products will be produced with the possibility of a greater range of application.

The designation "industrial talc" includes earth minerals of widely different chemical and mineral compositions.[4] Single particles of talc have a range of water content from 3.5% to more than 7% and slight differences in MgO and SiO_2 proportions. The chemical composition of a typical, relatively high grade, industrial talc is shown in Table 4.

TABLE 4 - Chemical Analysis of Industrial Talc[4]

Oxide	Percent
SiO_2	62.65
Al_2O_3	0.31
Fe_2O_3	-
FeO	-
CaO	trace
MgO	30.23
$Na_2O + K_2O$	0.20
L.O.I.	4.95
H_2O	4.87
CO_2	0.27

Most industrial talcs are mixtures of silicates and contain significant amounts of magnesia. Other minerals commonly found in talc ores are serpentine, chlorites, tremolite and carbonates calcite, dolomite and magnesite.

Approximate compositions of these materials are shown in Table 5.

TABLE 5 - Approximate Composition of Minerals[4]

Mineral (Weight %)	CaO	MgO	Al_2O_3	SiO_2	CO_2	H_2O
Serpentine		43		44		8-13
Chlorite		36	18	33		5-14
Tremolite	13	28		57		1.5-2.3
Calcite	56				44	
Dolomite	30	22			48	
Magnesite		48			52	

If some of these minerals, along with sulfides, sulfates, and iron and manganese oxides, are present in more than trace amounts, the use of a talc may be restricted or its value lowered. Occasionally, some minerals may give a chemical composition and other properties to the product which are highly desirable for a specific use. For example, a talc high in the mineral tremolite may be ideally suited for use in some paints and certain ceramics.

Because of its platey nature, talc increases the tensile and impact strength of filled polymers. Pure talc is relatively inert and remains undecomposed in acid. When heated, part of the water that is commonly present can be driven off with no change in optical or crystalline properties. Industrial talcs are produced from rocks with a wide range of grain size; the talc component and other minerals may be foliated, granular or fibrous. The fibrous and foliated forms are related to cleavage and partings of the minerals and, therefore, remain after the finest grinding.

Particle-size specifications for most uses require the talc to be minus 45 μm. The specification for paint is 99.8 to 100 percent minus 45 μm; while for rubber, ceramics, insecticides and enamels, 95 percent minus 45 μm is common. For wall tile, 90 percent minus 45 μm is required and roofing grades require minus 180 μm, with a maximum of 30 to 40 percent minus 75 μm.[3]

For the paper industry, talc must be free of chemically active compounds like carbonates, iron and manganese, possess a high reflectance and be free of abrasive impurities. For ceramics, talc must be low in iron, manganese and other impurities that would cause discoloration on firing. In the paint industry, specifications for talc pigment relate to chemical composition, color, particle size and oil absorption. A low carbonate content, nearly white color and controlled particle size distribution are also important. Nevertheless, because of the wide variety of paints, precise specifications for talc pigments are commonly based on agreement between supplier and consumer.

For use in pharmaceuticals and cosmetics, talc should be free of abrasive impurities and fibrous minerals which could be harmful when inhaled or ingested. Many applications, such as dusting agent for asphalt roofing and gypsum board, filler in drywall sealing compounds and auto-body patching compounds, use lower grade talcs and, therefore, the specifications for these uses are less strict.

REFERENCES

REFERENCES

1) Canadian Minerals Yearbook 1980; Energy, Mines and Resources Canada.

2) Canadian Mining Journal, Vol. 104, Feb. 1983.

3) Industria Minerals, December 1982.

4) Industrial Minerals and Rocks (Non-metallic other than fuels). Joseph L. Gillson, ed; 3rd edition; American Institute of Mining, Metallurgical and Petroleum Engineers, New York 1960.

5) Industrial Minerals and Rocks (Non-metallics other than fuels); Stanley J. Lefond, ed; 4th edition; American Institute of Mining, Metallurgical and Petroleum Engineers, New York, 1975.

6) Minerals Yearbook Centennial Edition 1981, Vol. I, Metals and Minerals; U.S. Department of the Interior.

PHASE II

Establishment of Particle Size Monitoring Methodology

Most of the information in this report has already been given in the summary volume. In fact, the only significant differences are the inclusion of additional particle size analyses of a number of cements and a note on the precision of the Blaine air permeability test procedure.

REQUIREMENTS (as defined by CANMET)

Establishment of Monitoring Methodology

"A laboratory evaluation of commercially available and experimental instruments and monitoring techniques and systems potentially applicable to real-time monitoring of fine particles in grinding circuits shall be made and either existing equipment shall be selected or modified or new equipment shall be developed for subsequent pilot plant studies or real-time circuit control. It shall also be required to develop a sound sampling strategy and ensure good execution."

The preparation of a detailed technical proposal and cost breakdown for the Phase III work is to be provided as part of this requirement. A preliminary description of the third phase is included below.

Development of Pilot Plant Systems (Description Only)

"A pilot closed circuit grinding system would be set up reflecting the best available state-of-the-art technology with respect to the needs of representative industrial minerals comminution. The plant would be instrumented for direct energy measurements and designed to allow modular introduction of experimental control systems and removal of material at various stages of comminution. Selected mineral products would be ground in the circuit with a record of total energy audit versus operating characteristics being established for each.

Monitoring/control systems to optimize the total energy consumption would be developed along with necessary software and hardware for their ultimate introduction into full scale plants. In essence, the pilot plant would become a "test-bed" for evaluating grinding control systems and procedures. Direct energy consumption would be immediately measured by instrumentation, indirect energy consumption would be measured or estimated off-line in parallel experiments related directly to the needs of the product user."

Introduction

The advantages of on-line control of milling circuits has been pointed out in a number of articles[1-4]. This interest in automatic control has given rise to development of a range of different types of equipment for on-line particle size measurement.

Davies[1] has identified 21 classes of equipment, classed on the basis of the principles used to sense and size the particles. This article, and earlier reviews[5] by the same author, describe the equipment in some detail.

Principles used to sense and size particles
1. Image replication and analysis
2. Electrical resistance change
3. Light scattering
4. Light obscuration
5. Light diffraction
6. Optical grating method
7. Beta-ray attentuation
8. X-ray absorption and fluorescence
9. Acoustic interference
10. Ultrasonic attenuation
11. Differential air classification
12. Hydroclone separation
13. Pulsating gas flow
14. Pressure drop in a nozzle
15. Transient and evaporative cooling of a hot wire
16. Impact and momentum measurement
17. Magnetic flux variations
18. Electrostatic ion capture
19. Glow discharge perturbation
20. Automatic sieve methods
21. Correlation techniques

Most of the instruments listed are either not directly applicable to the industrial mineral sector or not sufficiently proven to be regarded as commercially available. Thus, in order to focus the study, we investigated the status of on-line equipment development in North America and Europe. From this investigation, it was decided to direct attention to equipment based on light scattering and diffraction.

In addition, it was decided to study the status of automatic Blaine meters, which give a measurement of specific surface area rather than particle size, but could be used in control of mill circuits, particularly in cement plants.

As representative of light scattering equipment, the Microtrac, marketed by the Leeds and Northrup Company, was chosen because of its degree of development and commercialization in North America.

The Microtrac was evaluated under laboratory conditions. Its accuracy and repeatability were compared to the Sedigraph,* an instrument whose operating characteristics have been established over a long period.

No laboratory evaluation was made of automatic sampling equipment because a range of different types of samplers are commercially available and have been proven under plant conditions.

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* The Sedigraph 5000 is manufactured by Micromeritics Inc., Norcross, Georgia. It employs the sedimentation principle, with particles settling in a proprietary liquid and a beam of x-rays as detector.

Laboratory Comparison of Laser and Sedimentation Particle Size Analysis

The comparison of the two types of instruments was based on cement samples of which the 45 μm size had been determined by wet sieving, and other materials from the comminution study. The 45 μm size has been used as a quality parameter in the cement industry for many years. It has been accurately defined by the industry and by the U.S. National Bureau of Standards using electroformed micromesh sieves and, therefore, is a good reference point for establishing the accuracy of the Microtrac and Sedigraph.

The Microtrac can be used for wet or dry samples but, because of difficulties experienced in getting the dry sampling system to operate satisfactorily and concern about agglomeration of particles in the air stream, the comparison between the two instruments was carried out on slurried samples. Water, with a small quantity of detergent, was used as the dispersing medium for Microtrac samples. A proprietary liquid, Sedisperse A13, was used with the Sedigraph.

Sedigraph

Repeatability

To evaluate the repeatability of the Sedigraph, tests were made on a Portland cement from C.E.R.I.L.H.*, the research centre of the French cement industry.

Results obtained with the French cement are shown in the table overleaf. The particle sizes in the table are chosen to coincide with those detected by the Microtrac.

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* Centre d'Études & de Recherches de l'Industrie des Liants Hydrauliques.

Sedigraph - C.E.R.I.L.H. Standard Cement

Cumulative % finer than size shown.

µm	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Avg.	Mean Deviation*	Range
88	96.5	98.0	97.0	97.0	97.0	98.5	97.3	0.60	2.0
62	93.0	94.0	93.5	91.5	91.0	94.0	92.8	1.07	3.0
44	85.5	85.0	85.5	83.0	81.5	85.5	84.3	1.40	4.0
31	71.5	71.5	71.5	70.5	69.0	73.5	71.3	0.98	4.5
22	60.0	57.0	57.5	56.5	55.5	60.0	57.7	1.43	4.5
16	45.5	44.5	45.0	45.0	44.5	47.0	45.3	0.68	2.5
11	33.5	33.0	33.0	33.5	33.0	36.0	33.7	0.80	3.0
7.8	24.5	23.5	24.0	24.5	24.5	26.5	24.6	0.65	3.0
5.5	17.5	16.5	17.0	18.0	18.0	19.5	17.8	0.75	3.0
3.9	12.5	11.5	11.5	13.0	13.5	14.5	12.8	0.92	3.0
2.8	8.5	7.5	7.0	9.0	9.5	10.0	8.6	0.92	3.0

Each test result is an average of six readings.
* Measure of dispersion.

Accuracy

The accuracy of the Sedigraph was determined from results obtained on a C.E.R.I.L.H. cement which is used as a standard for particle size analysis.

The results are given below.

Sedigraph - C.E.R.I.L.H. Cement

Cumulative % finer than size shown.

µm	Mean Sedigraph Value (%)	Assigned Value (%)
88	97.3	94.5
62	92.8	89.5
44	84.3	82.0
31	71.3	70.0
22	57.7	57.0
16	45.3	44.5
11	33.7	35.0
7.8	24.6	25.5
5.5	17.8	20.0
3.9	12.8	14.0
2.8	8.6	9.5

A further evaluation of Sedigraph accuracy was made from the 45 μm (#325 mesh fineness) determination on the six Portland cements. The #325 mesh fineness had been determined by wet sieving at ten separate laboratories as part of a Canada Cement Lafarge inter-laboratory program. Sedigraph and #325 mesh results are compared in the following table.

Wet Sieving v. Sedigraph at 45μm

Sample No.	#325 (45μm) % Passing	Sedigraph % finer than 45μm
240	94.3	95.2
241	98.1	98.0
277	94.9	94.1
281	86.3	85.8
287	91.1	90.0
294	95.3	95.1

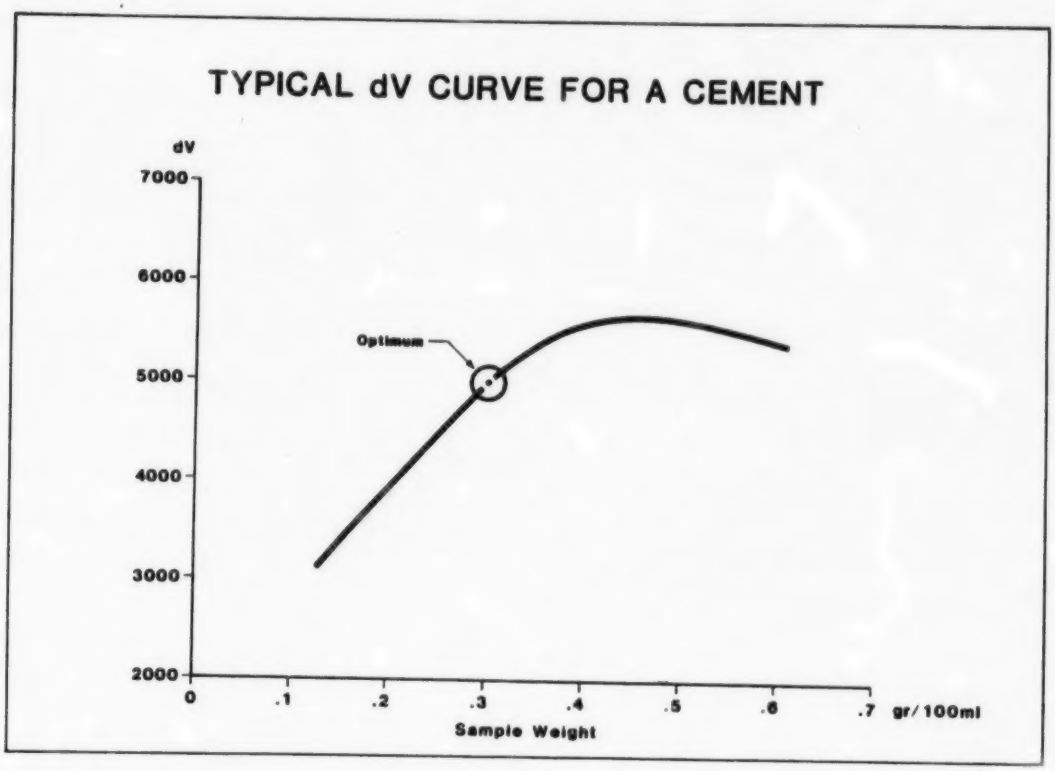
It is concluded from the results that, over the particle size range under study, the Sedigraph has both good accuracy and repeatability.

Microtrac

The Microtrac results are influenced by the weight of sample (as opposed to the Sedigraph which is relatively insensitive to sample weight). The manufacturer stresses the importance of the optimum weight of sample, and the instrument is equipped to indicate this optimum in the form of a number called "dV".

The dV number is defined as "a volume response giving an uncalibrated indication of the amount of particulate matter in the system". With the Microtrac, it is important that sample loading be low enough to keep main-beam attenuation and multiple light scattering at non-critical levels but high enough to achieve good resolution at the diffraction angles involved.

Optimum sample loading is obtained by plotting the dV number against variations in sample weight. The recommended sample weight is that near the peak of the resulting curve. A typical dV curve is shown in the figure below.



Results of dV and optimum loading weights for the six test Portland cements are given below. Densities for Portland cements are constant at 3.15 g/cm^3.

Optimum Loading and dV for Portland Cements

Sample No.	Surface Area Blaine (cm^2/g)	dV	Optimum Sample Weight (g)
240	5490	.2396	0.15
241	5290	.2483	0.15
277	4500	.4006	0.25
281	2980	.5645	0.30
287	3420	.4518	0.30
294	4010	.3794	0.25

The results indicate that dV and optimum loading weights vary in relation to the surface area of the material in spite of a constant density.

Optimizing the dV response of the Microtrac will be an important parameter in any on-line application where wide ranges of fineness could be found.

Repeatability

Repeatability of the Microtrac for the analysis of a standard cement is demonstrated in the next table, which shows that the variation in Microtrac results is similar to the Sedigraph for the standard cement.

Microtrac - C.E.R.I.L.H. Standard Cement

Cumulative % finer than size shown.

µm	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Avg.	Mean Deviation*	Range
88	100	100	100	100	100	100	100	0.00	0.0
62	98.1	100	99.4	100	99.8	100	99.6	0.52	1.9
44	94.7	98.1	95.8	96.5	96.2	96.7	96.3	0.77	3.4
31	85.7	87.1	87.5	86.1	87.0	85.8	86.5	0.67	1.8
22	71.1	71.0	73.4	72.6	72.0	73.0	72.2	0.82	2.4
16	57.0	58.9	59.1	58.4	58.0	58.3	58.3	0.52	2.1
11	41.2	42.6	42.1	42.2	42.6	42.0	42.1	0.35	1.4
7.8	28.5	29.1	29.9	29.3	28.0	29.5	29.1	0.52	1.9
5.5	17.1	18.4	20.4	18.7	17.6	19.3	18.6	0.88	3.3
3.9	8.6	9.5	10.5	9.8	9.3	10.4	9.7	0.55	1.9
2.8	4.4	4.7	4.4	4.1	4.3	3.9	4.3	0.20	0.8

Each test result is an average of six readings.
* Measure of dispersion.

Accuracy

The Microtrac results for the standard C.E.R.I.L.H. cement are compared with the assigned values in the following table.

Microtrac - C.E.R.I.L.H. Standard

Cumulative % finer than size shown.

Particle Size (µm)	Mean Microtrac Value (%)	Assigned Value (%)
88	100	94.5
62	99.6	89.5
44	96.3	82.0
31	86.5	70.0
22	72.2	57.0
16	58.3	44.5
11	42.1	35.0
7.8	29.1	25.5
5.5	18.6	20.0
3.9	9.7	14.0
2.8	4.3	9.5

The Microtrac results are considerably higher than the assigned values from 88 to 7.8 µm. Below this particle size, the results are lower than assigned values.

An estimation of Microtrac accuracy was also made by evaluating its performance at the 45 µm size. The following table, comparing wet sieving, Sedigraph and Microtrac results for the six test cements, confirms that the Sedigraph is more accurate for this particle size.

Wet Sieving v. Microtrac at 45 µm

Sample No.	No. 325 (45 µm) % Passing	Microtrac % Finer Than 45 µm
240	94.3	100.0
241	98.1	98.8
277	94.9	97.0
281	86.3	87.5
287	91.1	97.2
294	95.3	94.8

On the average, Microtrac results are consistently higher than those of wet sieving, but not to the extent seen with the standard cement.

The fact that the Microtrac gives somewhat higher readings than the Sedigraph is confirmed by the results of the tests on four Type 10 and two Type 30 cements.

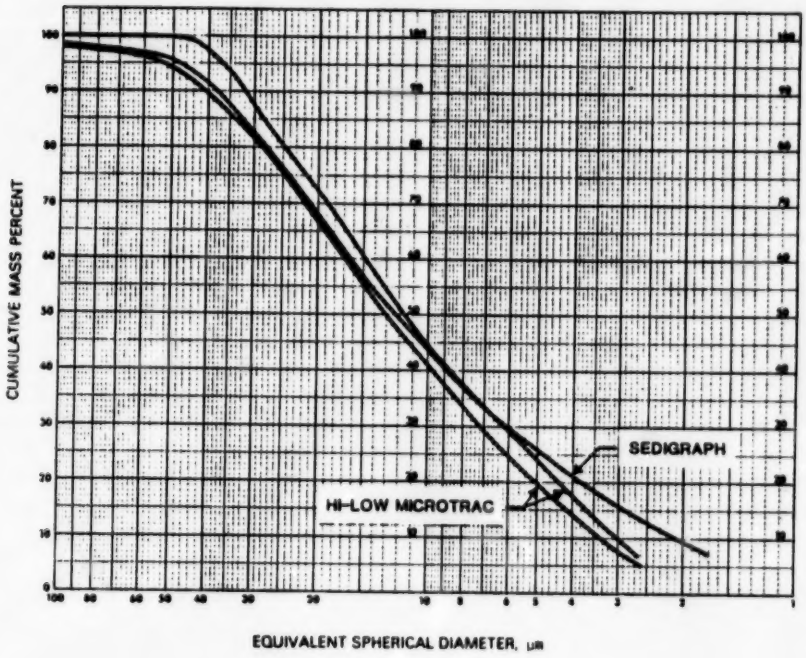
The Blaine and % passing 325 mesh are as follows:

Sample Code	Blaine M^2/kg	% Passing 325 mesh
Type 10		
Interlab 277 R	450	94.9
Interlab 281	300	86.3
Interlab 287	343	91.3
Interlab 294	401	95.3
Type 30		
Interlab 240	524	94.3
Interlab 241	529	98.1

The results from the two instruments are shown graphically on the following pages.

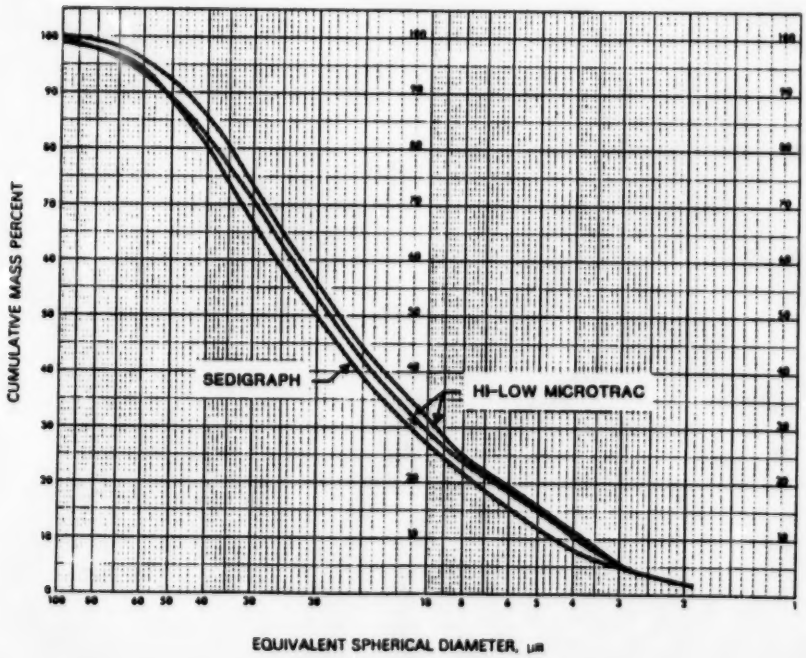
INTERLAB 277 R

% Passing 325 = 94.9 Blaine 450 M^2/kg



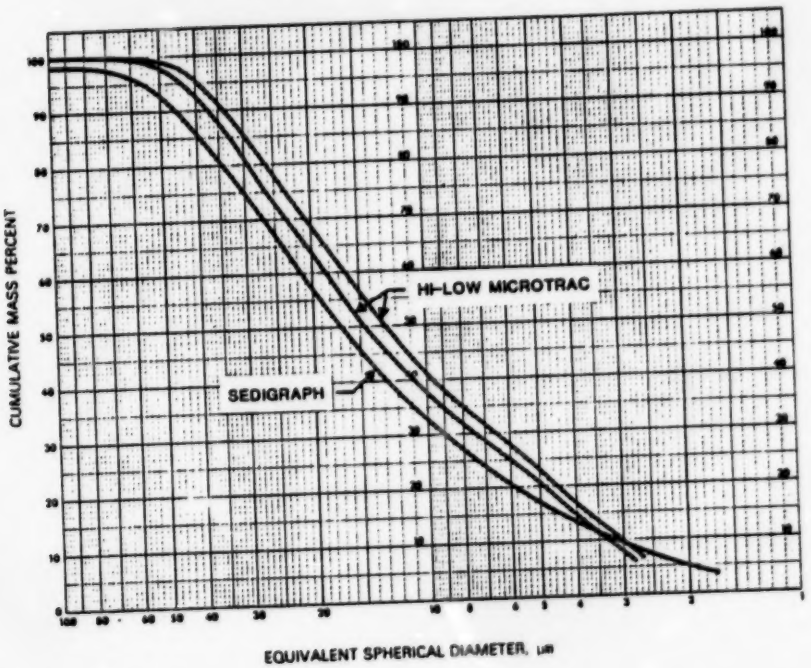
INTERLAB 281

% Passing 325 = 86.3 Blaine 300 M^2/kg



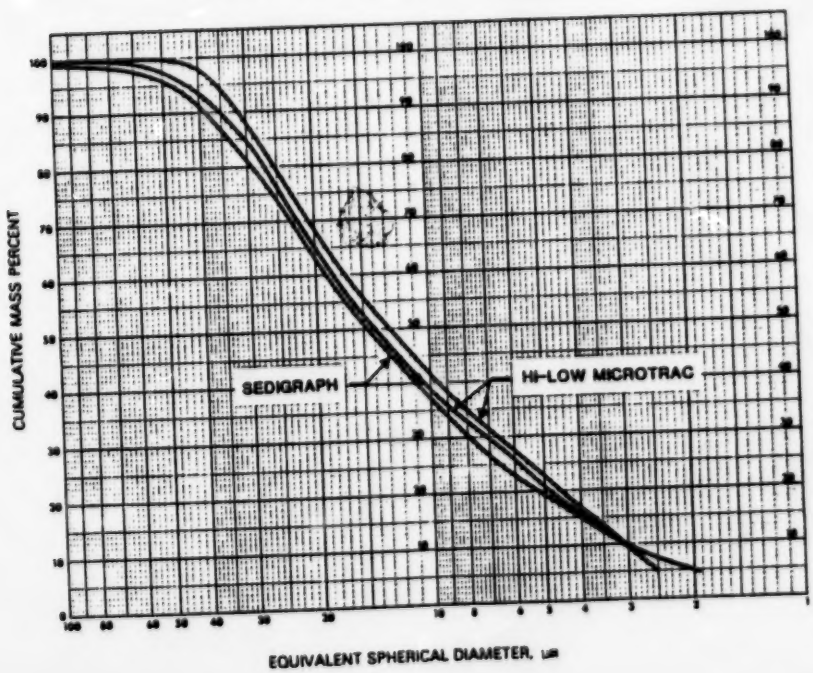
INTERLAB 287

% Passing 325 = 91.3 Blaine 343 M^2/kg



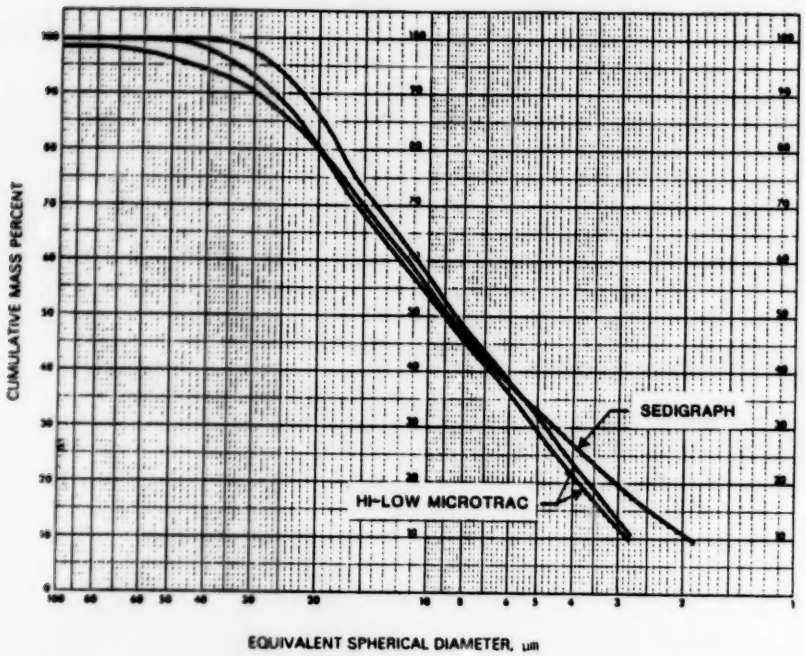
INTERLAB 294

% Passing 325 = 95.3 Blaine 401 M^2/kg



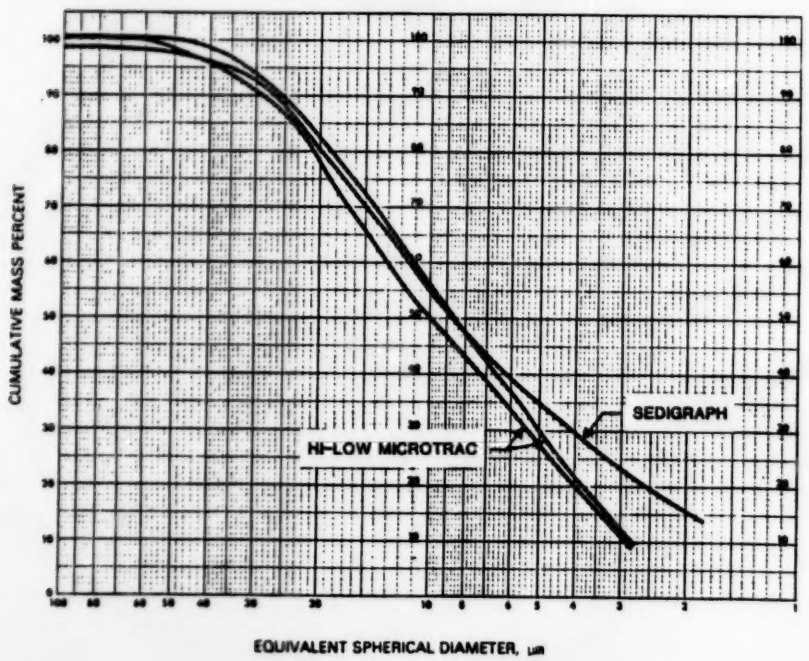
INTERLAB 240

% Passing 325 = 94.3 Blaine 5240 M^2/kg



INTERLAB 241

% Passing 325 = 98.1 Blaine 5290 M^2/kg



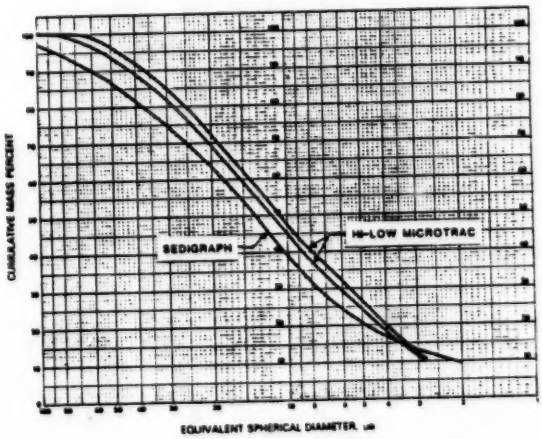
Particle size analysis of non-cement materials

A comparison of the results from the Microtrac and Sedigraph analysis of the following materials

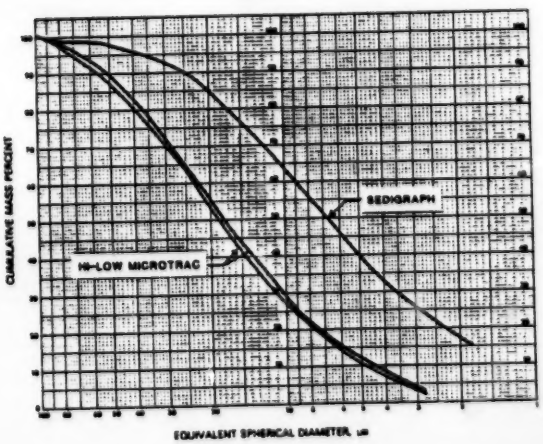
- cement raw mix
- mica
- limestone, limestone (calcite)
- talc
- nepheline syenite

are shown in the graphs below. The "hi-low" Microtrac curves give the range of results obtained from a set of samples.

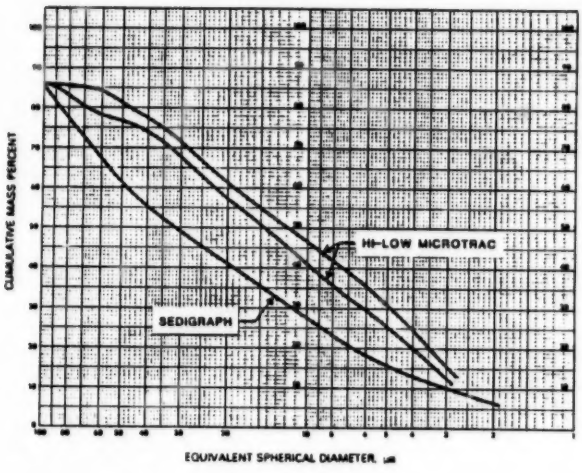
CEMENT RAW MIX



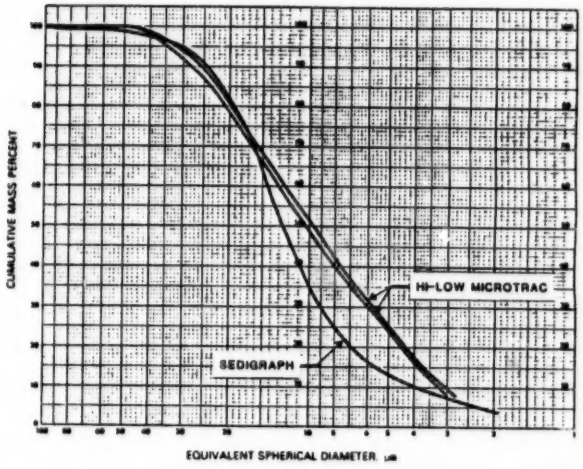
MICA



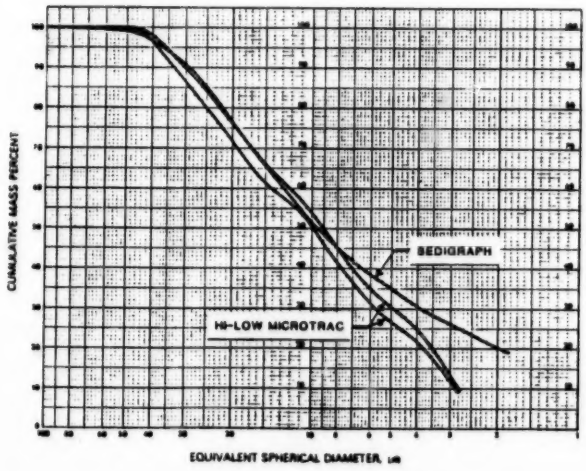
LIMESTONE



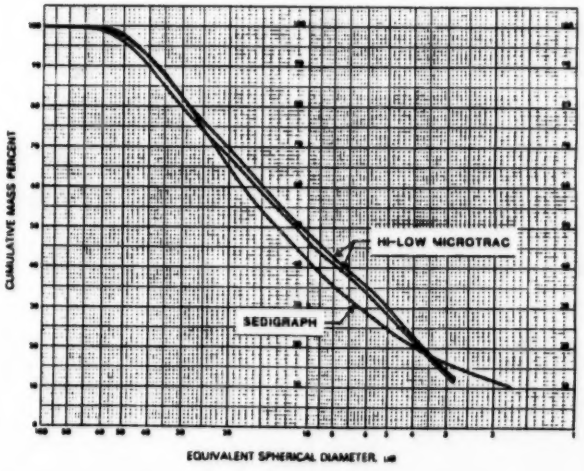
TALC



LIMESTONE - (Calcite)



NEPHELINE SYENITE



For the Portland cement raw mix, composed of a mixture of limestone and shale, No. 325 wet sieving indicated 81.2% passing at 45 μm. The Sedigraph and Microtrac gave 83.8% and 93.0%, respectively. This result is consistent with earlier data indicating that the latter is less accurate at the coarse end of the scale.

The results for the mica sample show the largest difference between the two instruments. The wide difference in results could be attributed to the shape of the particles affecting sedimentation.

There is also considerable difference in results for the Domtar limestone sample. Differences like this are difficult to explain without further exploration, but could be due to poor dispersion in water of the Microtrac samples.

In general, the reproducibility of the Microtrac results for the industrial minerals was found to be within the ±5% range quoted by Leeds and Northrup[9].

On-line Application of Particle Size Analysers

On-line applications of a number of types of particle size analysers are summarized in the table below.

ON-LINE APPLICATIONS			
CLASSIFICATION BASED ON PARTICULATES CONCENTRATION IN THE SENSING REGION	MODE		CURRENT STATUS
	WET	DRY	
I. Low Concentration Methods (single particles)			
- Electrical Conductivity	X		- Restricted to contaminants.
II. High Concentration Methods (5-70% by weight)			
- Hydrocyclone	X		- Tested in plant environment[6].
- Automatic Sieving	X		- Not in current use. Min. 100 μm particles.
- Ultrasonic Attentuation	X		- Tested in plant environment[6] (Armco Autometrics).
- Beta-Ray Attentuation	X		- Not in use.
III. Intermediate Concentration Methods (0.1% by weight)			
- Light Diffraction		X	- Cilas; not in current use.
	X	X	- Microtrac: currently installed in a number of locations.
- Differential Air Flow		X	- Metzger & Leschonski's Model: commercialization in process[8].
IV. Air Permeability (Blaine meter)		X	- Japanese development - unknown; presumed abandoned
		X	- Fuller's mid 70's model: abandoned.
		X	- Milltronic's early 70's model: abandoned.
		X	- HolderBank - Hasler: currently in plant testing.

The first category is applicable to low concentrations of particles and not directly relevant to industrial mill circuits. The high concentration methods were not explored further because they do not appear to be under active development at present.

Of the remaining two categories, laser systems have been tested under plant conditions, a differential air flow method is reported to be ready for commercialization and at least two automatic Blaine meters are installed in plants.

Laser Systems

The Microtrac is the most widely commercialized particle size analyser in this category. In North America, some 400 units are reported to have been sold to a wide range of industries, including explosives, food, chemicals, minerals and oil.

A number of industries, where on-line monitors are installed, were contacted. The applications are shown in the table.

ON-LINE MICROTRAC APPLICATIONS

INDUSTRIES	PLANT & LOCATION	PARTICLE CHARACTER-ISTICS	MODE	
			WET	DRY
Cement	- Calavares Cement Redding, California, USA	80-90% passing 325 mesh		X
	- Florida Mining Brooksville, Florida, USA			X
	- Lonestar Cement Seattle, Washington, USA			X
	- Blue Circle Industries Greenhithe, Kent, UK			X
Talc	- Talc-de-Luzenac Luzenac - Ariège, France	10-50 µm		X
Minerals (Tailings)	- Lornex Mining Logan Lake, B.C., Canada	2.7-300 µm	X	
Alumina	- Alcoa Tech. Centre Alcoa Centre, Pa, USA	--	-	-
Iron Ore	- Iron Ore Company Newfoundland, Canada	65% passing 44 mesh	X	
	- Bethlehem Steel Bethlehem, Pa, USA	--	X	

The results from the talc and iron ore plants were reported to be satisfactory, while the cement industry and mine tailings still had problems to overcome. The main difficulties cited for the dry mode were control and presentation of the sample in a dispersed form to the laser beam. In the wet mode, daily clean-up of the sample cell was necessary and abrasion was a problem. Very little quantitative data describing the performance of the instruments was available.

In general, some concern was expressed about the ability of the instrument to stand up to the heat, dust and vibration in a plant environment.

Permeability Systems (Blaine meter)

Hasler Frères SA have developed an automatic Blaine meter. One of these meters has been installed at a German cement plant since 1982 and is, according to a Hasler report[10], operating well.

The objectives of the installation were;

1) to insure a constant fineness of the finished cement within a divergence of ± 100 for three different Blaines (3100 - 4300 - 4900 cm^2/g);

2) to have maximum possible output at these finenesses;

3) to reduce the energy consumption of the mill to the minimum;

4) to be adjusted easily to different types of input material;

5) to enable the system to be controlled remotely.

The mill being controlled has two compartments, a 3500 hp motor and an output of about 100 t/h. It is equipped with a Pfeiffer Turbo separator.

Ciments Lafarge France commissioned a Hasler automatic Blaine meter, at a cement plant in Marseilles, in early 1983. No reports on the performance of the equipment are available yet.

The Sedigraph is an accurate instrument, giving good reproducibility of results in the 100 - 2 μm range. Because of the time required to prepare and run samples, it is best suited for a laboratory role. However, it provides a useful reference for evaluating the performance of other instruments.

Laser based instruments of which the Microtrac is the most developed and commercialized in North America, could be used for on-line particle size analysis in the industrial minerals industry, if the problems associated with dispersing the particles and presenting a dry sample of suitable concentration to the sensor can be overcome.

The reproducibility of the Microtrac results is similar to the Sedigraph, but generally gives higher readings.

It can span a wider range of particle sizes, 200 - 2 μm, compared to 100 - 2 μm for the Sedigraph.

The Microtrac scanning time can be as low as 25 seconds, compared to 25 minutes for the Sedigraph.

The Microtrac has apparently been tried in a number of on-line applications but with limited success.

Automatic Blaine meters are installed in at least two cement plants in Europe. One is reported to have performed satisfactorily since 1982. The other was commissioned in 1984.

The Blaine meter gives a measure of specific surface area rather than particle size and has a slower response time than the Microtrac but could be used for mill circuit control, particularly in the cement industry.

APPENDIX

The precision of the Blaine air permeability test.

PRECISION

Blaine Air Permeability Determination

ASTM has found the precision for the Blaine Air Permeability C 204 Test Method to be:

Single Operator

One Sigma Coefficient of Variation (1S%)	1.2%
Difference Two Sigma Coefficient of Variation (D2S%)	3.4%

Multilaboratory

One Sigma Coefficient of Variation (1S%)	2.1%
Difference Two Sigma Coefficient of Variation (D2S%)	6.0%

The One Sigma Coefficient of Variation is defined as:

the standard deviation expressed as a percent of the average of test results on a single sample.

The Difference Two Sigma Coefficient of Variation is defined as:

the difference between two individual test results, expressed as a percent of their average, that would be equaled or exceeded in only 1 case in 20.

The Difference Two Sigma Coefficient of Variation (D2S%) is calculated by multiplying 1S% by $2\sqrt{2} = 2.83$.

Canada Cement Lafarge Ltd., from its Interlaboratory Program has found the precision of the Blaine determination to be:

Multilaboratory

One Sigma Coefficient of Variation (1S%)	1.6%
Difference Two Sigma Coefficient of Variation (D2S%)	4.5%

These results were generated from Blaine determinations on approximately 40 Portland cements by 12 laboratories over an eight year period.

The improved Canada Cement Lafarge precision reflects the high degree of standardization among Company laboratories.

It is felt, however, that single operator precision for Canada Cement Lafarge would be at the same level as found by ASTM.

There is no general statement that can be made for accuracy. For multilaboratory results, accuracy and precision are almost synonomous. This may not be the case for single operator results.